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Flood Risk Mapping in the Amazon

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Abstract

Floods are part of the natural and cultural life in the Amazon. However, the issues and management of fluvial-disaster risks are poorly studied. Among the reasons for the lack of studies, the Amazon region has several gaps in information ranging from inadequate regional maps to spatially unsystematic local data. Flood patterns differ in urban and rural areas. Severe large-scale flooding took place during the previous and the current decades, such as those that occurred in 2009 and 2012. Between 1991 and 2010, official recorded data indicate about 3,292,888 people were affected in 6 regional states of the Amazon (Acre, Amapá, Amazonas, Pará, Rondônia, and Roraima) considering 7 different hazards. Because of the extensive damages, the national government started a mapping program for cities in Brazil that have a history of facing significant flood risks. The aim of this chapter is to analyse the flood-risk mapping conditions in the Amazon.

Keywords: Amazon region, disaster risk, flood hazard, vulnerability, risk mapping, risk management, urban planning

1. Introduction

Brazil recorded 4691 flood events between 1991 and 2012, which represent 12% of all natural hazards in the country. In the Amazon, floods affected around 2379 people [1]. However, rivers are a fundamental component of Amazon life. Many highly populated cities are located along the major rivers and floodplains on the Amazon and Tocantins river basins, which together house over five billion inhabitants [2] (**Figure 1**).

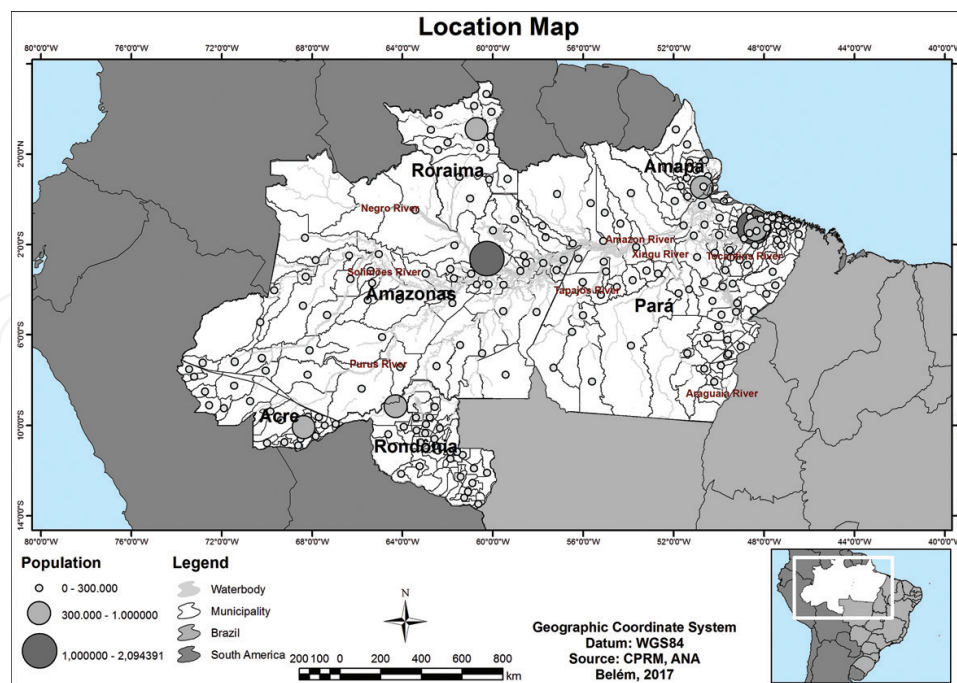


Figure 1. Study area showing the hydrographic networks and the pattern of the cities located nearby important rivers in the northern Amazon region.

Risk is a function of the probability that a particular hazard (such as flooding) might take place and the vulnerability of a particular location to being negatively affected by that hazard [3]. The likelihood of floods generating damage when river water overflows a river bank is a risk. Impacts are the generally negative effects of a hazard taking place in a given locale. Impacts vary from immaterial to material losses across cities such as individuals and families losing their homes and other dwellings, or losing access to such dwellings.

Included among material damages in urban areas are the destruction of public and private infrastructures, disruption of normal traffic flow, and reduction of accessibility to various locations and city spaces [4]. In rural areas, impacts include disruption of agricultural production, depopulation because of migration to the cities, and inflation of food prices at the local markets due to damage or destruction of crops near the floodplains. Small farming communities are particularly susceptible to extreme flood events because of the lack of adequate infrastructure for transporting people and their goods to industrial and commercial centers, the lack of information about extreme weather events at the community level, and the lack of sufficient economic resources to endure the effects of prolonged environmental catastrophes [5].

Since 2012, mapping flood risks has been one of the objectives of the National Program for Risk Management and Response to Disasters. Program priorities include investments in preventing, providing alerts for, monitoring, and responding to natural hazards. The program goal is to reduce the negative impacts of natural calamities on populations that live in risk-prone areas and guarantee the safety of communities from these calamities [6].

Therefore, response actions need precise physical aspects. Flood-hazard background information prioritizes the measures of frequency and magnitude of severe flooding, as well as the

hydrodynamic and climatic scenarios [7, 8]. Response actions focus on the use of geoscience data and on structural engineering measures [9].

Another way to reduce risk is investments in prevention. Examples are the expansion of monitoring and warning systems, systematic mapping of high-risk areas [6], and preparation of vulnerability assessments. Vulnerability depends on the scale, time, and space units of analyses such as individuals, households, regional areas, and system-wide conditions [10]. Vulnerability definitions vary according to research approach and methodologies.

The International Strategy for Disaster Reduction (UN-ISDR) defines vulnerability as the combination of physical, social, economic, and environmental factors or processes that increase the susceptibility of a community to the impact of hazards [11]. The use of indicators is a common approach for vulnerability measurement [12, 13]. At a national scale, the social aspect of vulnerability displays higher levels of negative indicators for the Amazon region when compared to cities in the south-western region of Brazil [14].

2. Flood hazards in the Amazon region

Floods occur in the Amazon and Tocantins river basins in the northern region of Brazil. The Amazon river basin has flood water levels variability between 2 and 18 m [15]. The Amazon river receives the discharge of other big rivers (e.g., Negro and Tapajós), and floods occur periodically depending on the seasonal rainfall for each river. Floods usually occur in June for the Amazonas, Branco, and Negro rivers. At the Macapá station, tidal influences mean that river seasonality is barely noticeable throughout the year (**Figure 2**).

The historical data series varies according to the station. The water-level data from stream gauging stations cover 112 years at Manaus (1902–2014); 48 years at Boa Vista (1967–2015), Barcelos (1967–2015), Rio Branco (1967–2015), and Madeira (1967–2015); 39 years at Macapá (1976–2015) and São Felix (1977–2016); and 20 years at Baião (1971–1991). Some of the stations have been deactivated [16].

On many southern rivers and tributaries, water levels remain high during the first semester. Highest river stages occur during February and March, and there are more incidences of floods during this period (**Figure 3**). Flooding in the Tocantins river basin is limited to its eastern area with the Tocantins river being the main tributary that reaches a 10-m water level.

In 2009, the Amazon river basin experienced extreme flooding. At the Manaus station of the Negro river, the water level reached 29.75 m, the highest mark in 107 years since stage data became available [8]. At the reference point of the Obidos gauge station, the river reached 8.42 m. For the Tapajós river (Santarém station), the highest water-level mark was 8.31 m [4].

A complex combination of factors contributed to these recent extreme-hazard events; namely, large- and regional-scale climatic events, unusual flood mechanisms that produced complex interactions in time and space between the main system and its tributaries [7, 8], and recent urban growth without adequate planning. Long-term climate models show extreme precipitation events over the Amazon region [17].

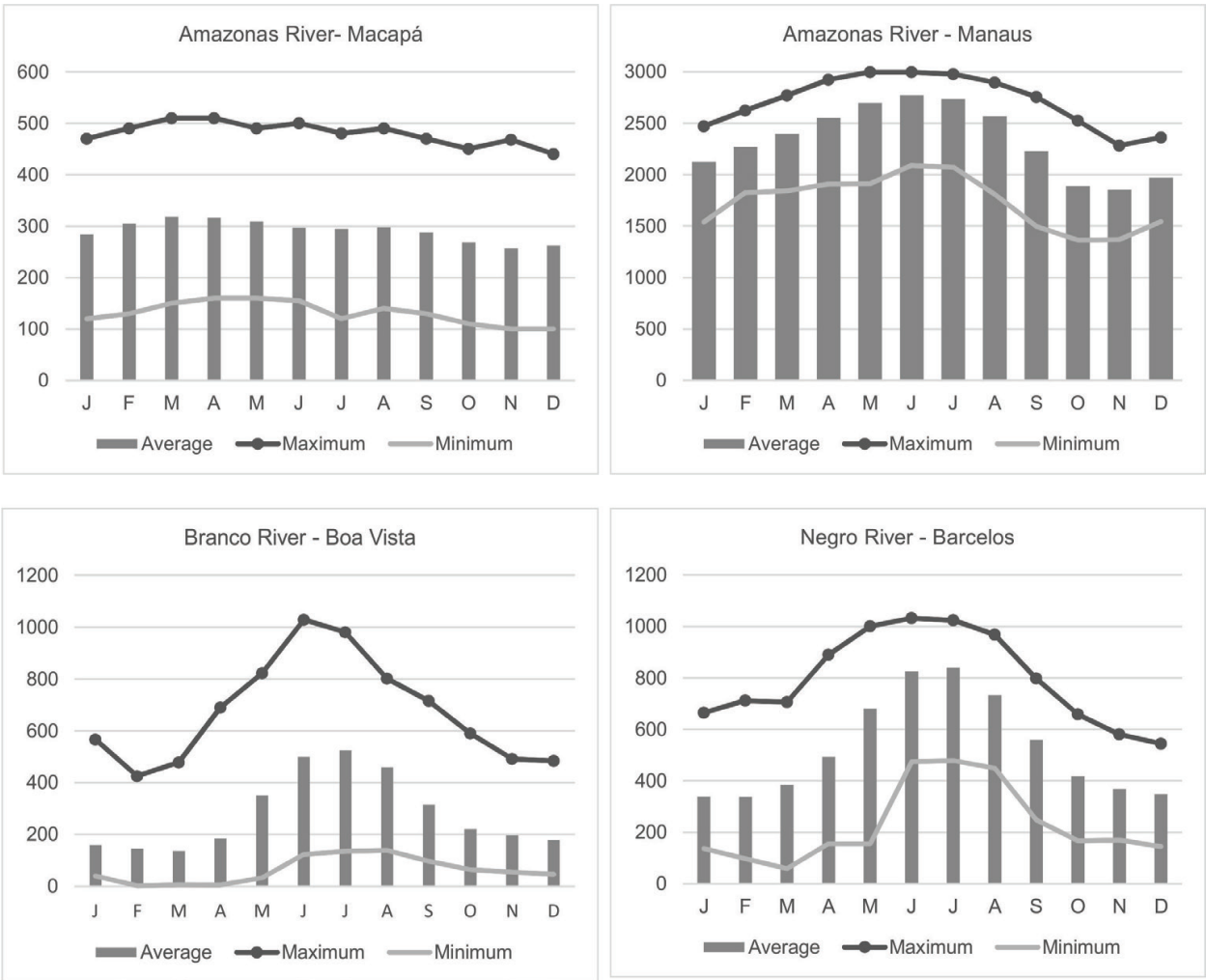


Figure 2. Historical river-level fluctuations (in cm) for the Amazon, Negro, and Branco rivers and their northern tributaries.

Landsat and shuttle radar topography mission (SRTM) data were used to define aspects of the morphologies of the fluvial systems in the Amazon and to construct the corresponding hydrodynamic models for these systems [18, 19]. Nevertheless, detailed geomorphologic maps that are fundamental to refining the fluvial models were not available [20]. For down-scaling analysis, susceptibility maps for floods at 1:50,000 scale became available for some municipalities since 2013 [21]. The analysis covers 23 urban municipalities covering respective areas that have high, moderate, and low susceptibility to flooding. The methodological approach includes hypsometric, declivity, geomorphological, and drainage analyses [22–24]. Currently available status-of-susceptibility flood maps include 18 municipalities from Pará, 2 from Amapá, and 1 each from Acre, Rondônia, and Roraima.

The National Water Agency produced a flood-hazard atlas considering the frequency of floods and the impacts probability associated with each part of the river. The flood frequency corresponds to 5, 10, or more years of recurrence intervals, and the impact was measured according to the damage extension. The results aggregate the flood severity assessment according to international terminologies [25].



Figure 3. Historical river-level fluctuations (in cm) for the Acre, Madeira, Tocantins, and Xingu rivers.

In total, 68 different rivers were integrated in the analysis and 4756 km of river extension is considered with high impacts and frequencies to flooding (**Table 1**). The percentage for river high-hazard stretches are 27% for Acre, 30% for Amapá, 16% for Amazonas, 10% for Pará, 37%

State/flood-hazard stretch (km)	Low	Medium	High
Acre	3014	1241	1599
Amapá	7	819	362
Amazonas	690	7037	1555
Pará	1034	6304	813
Roraima	38	120	96
Rondônia	98	625	331
Total	4881	16146	4756

Table 1. Flood hazard stretches for rivers in the Amazon region grouped according to state.

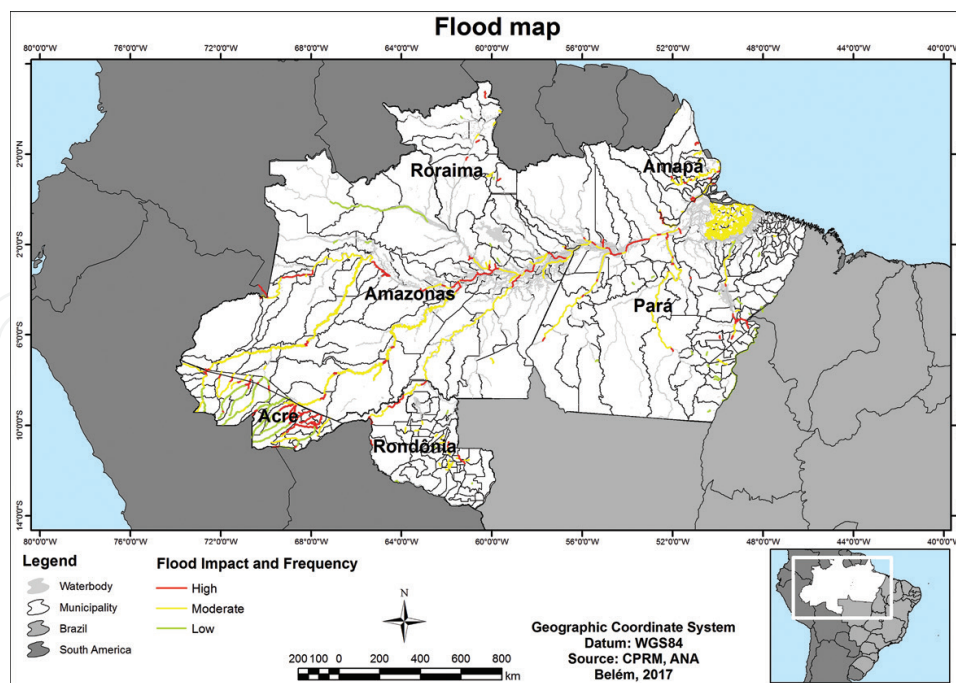


Figure 4. Flood map with parts of the river more susceptible to floods and impacts based on ANA data.

for Roraima, and 31% for Rondônia. The map is at national scale displaying areas with low, medium, and high impact frequencies [26] (Figure 4).

3. Vulnerability in the Amazon

Vulnerability is multidimensional and refers to social, economic, environmental, and physical categories [11]. Socio-economic vulnerability often describes the characteristics of people or groups of peoples [27]. Environmental vulnerability refers to natural-resources depletion and degradation [28]. Physical vulnerability refers to the susceptibility of particular locations to particular hazards and therefore represents the civilian infrastructure of a given place.

To deal with diverse research frameworks, the index of methodologies links natural-hazard risks and vulnerabilities. This means that when an extreme event leads to impacts, the latter is determined by the hazards aspect and by the respective vulnerabilities of communities, societal groups, or civilian infrastructures to such impacts [29].

Quantifying social vulnerability using various indicators can help identify which places are most vulnerable and which dimensions of social vulnerability are most relevant and therefore constitute the key drivers for change [30]. The Amazon region has 41% of its municipalities that are considered to have high social vulnerability. The analysis considered urban infrastructure, human capital, incomes, and work status as indicators [31]. This high percentage signifies a very low to medium-low Human Development Index (HDI) rating for rural and urban areas in the Amazon [32].

For a specific natural-hazard assessment, the Amazon region also has a very high social-vulnerability index. The indicators were (among others) gender, race and ethnicity, employment loss, social dependency, and migration rate [14]. Vulnerability to floods in rural communities is determined based on residency patterns, access to fishing and planting grounds, access to transportation and markets, water quantity and quality, and the prevalence of infectious diseases [33].

In large cities in the Amazon estuary, vulnerability was measured considering indicators of exposure (places and people located at hazardous areas), socio-economic situation, and condition of civilian infrastructure in terms of the availability and quality of sanitation services and housing structures (**Figure 5**). In these urban spaces, around 37,000 people live under very high-vulnerability conditions and 988,000 people live under high-vulnerability conditions [34].

Previous studies compiled for several locations along the Amazon coast in Pará state utilized vulnerability indices in addition to spatial information on floods and storm surges related to climate change and structural vulnerabilities [35]. Downscaling studies in vulnerability use methodological approaches based on the social-vulnerability index and an index on responses to hazards [36], on a methodological approach for community participation in flood mapping [4], and on a hazard-response identification scheme for urban planning for natural disasters issues [37].



Figure 5. The first and second photos showing Manaus (Amazonas state) infrastructure livelihood patterns and structural measures for accessibility in the central areas during the 2012 flood (photos in clockwise direction: CPRM, 2012). Santarém city (Pará state) during the 2012 flood showing wooden bridges and a view taken from the dike in front of the city during the 2009 flood (photos in clockwise direction: Milena Andrade 2012, Santarém Civil Defense 2009).

An effective vulnerability reduction plan should include adaptive capacity assessments. The human capacity to prepare for, respond to, and recover from natural disasters highlights local characteristics and situations [12, 38]. The structural and nonstructural measures for coping with hazards result from adaptive capacity. Pilot local-scale studies in the Amazon take into account qualitative variables and the influence of community participation in vulnerability assessments. These studies identify local knowledge as fundamentally important in coping and adaptation strategies and vulnerability reduction [4, 39].

4. Sectors of risk in the Amazon

The Geological Service of Brazil (CPRM) is responsible for mapping flood hazard-risk areas following the prevention criteria in the National Plan for Management and Response for Natural Hazards. The selection criteria for mapping emergency areas included the numbers of fatal victims and affected people, decreed state or level of emergency and calamity, and the official assistance requests from municipalities [40]. Between 2012 and 2016, CPRM mapped 1206 municipalities all over Brazil, of which 140 are located in the Amazon region.

Considering Pará, Amazonas, Acre, Rondônia, and Roraima states, around 180,000 people live within 418 risk sectors inside 99 municipalities with either high or very high risk of flooding [6] (Figures 6 and 7).

To delineate the risk sectors, the methodology included previous classifications was proposed in Refs. [41–43]. Some adaptations were necessary for the risk sectors in the Amazon region that considered the following situations: a riverine community’s location within a large floodplain, local water-level historical observations in existing infrastructures, lack of drainage and sanitation systems, household infrastructure fragility to flood effects (for wooden or brick houses),

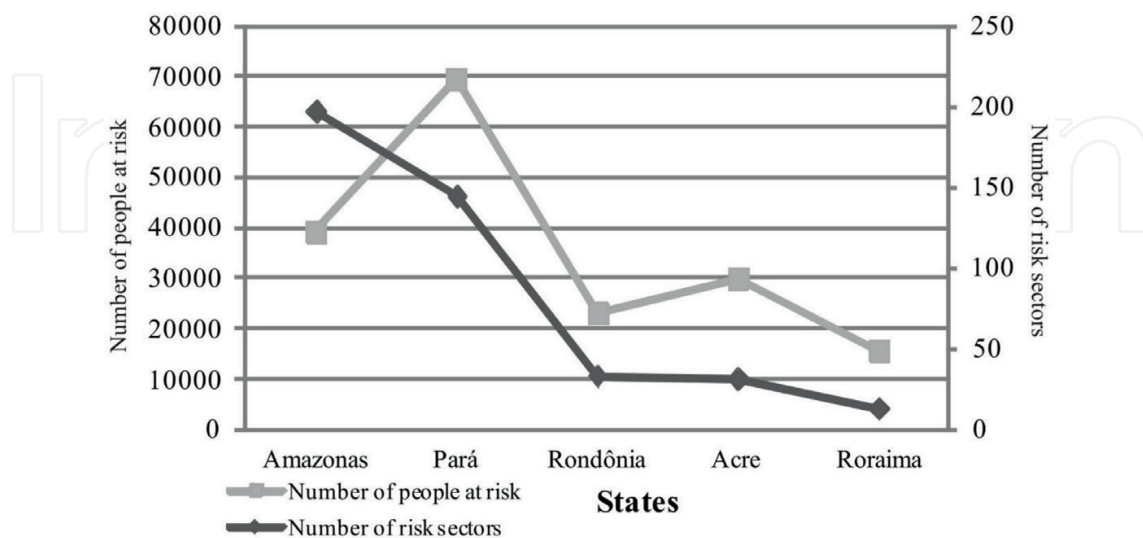


Figure 6. Graph of numbers of people in risk sectors of Amazonas, Pará, Rondônia, Acre, and Roraima states.



Figure 7. Sectors of risk in Eptaciolândia (Acre state) during the 2015 flood and Marabá City (Pará state) during the 2011 flood (photos in clockwise direction: Eptaciolândia and Marabá Civil Defense, respectively).

and measures of material and immaterial losses [6]. Very high-risk and high-risk areas were prioritized in the sector-mapping program because of the immediate need to prevent fatalities in these areas during hazard emergencies (**Figure 8**).

A very high-risk designation corresponds to a drainage with a high frequency (at least three events in the last 5 years) of flooding and a very high-damage probability because of the presence of vulnerable structures. High risk corresponds to a drainage with a moderate frequency (at least one event in the last 5 years) of flooding and a high-damage probability because of the presence of vulnerable household structures. Moderate risk corresponds to a moderate frequency (at least one event in the last 5 years) and low susceptibilities of structures to flood damage. Low risk corresponds to the absence of flood

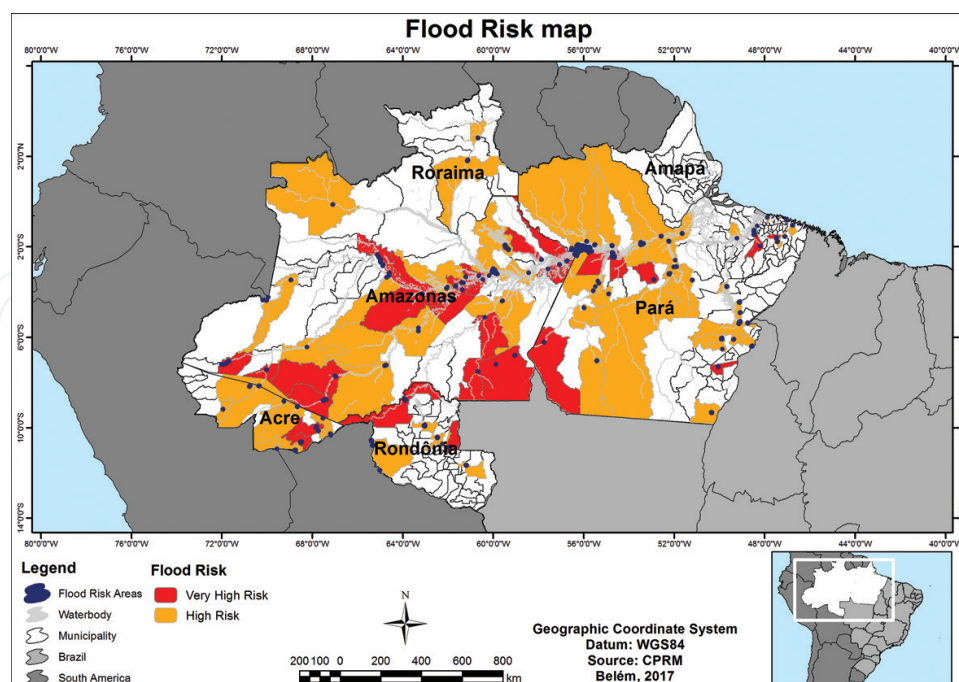


Figure 8. Map of municipalities in very high-risk and high-risk areas that are prone to flooding, according to CPRM data.

events in the last 5 years and the absence or presence of structures with low susceptibility to flood damage [43].

5. Conclusions

This study presented the developments in flood-risk mapping in the Amazon region. Flood-risk mapping projects are mostly by the national program for disaster reduction and counts on the support of national institutions. The effort to reach a nationwide methodology is a challenge due to the regional differences in Brazil.

Background information on flood hazards rely on fluvial water-level data taken along the river basins, on delineation of flood hazard-prone areas presented on 1:1,000,000-scale maps, and on semi-detail (1:50,000 scale) flood susceptibility maps for specific locations. These maps are the starting point for identifying critical areas for detailed hydrologic modeling. Extreme weather events have the potential to cause worse impacts on these high flood-risk areas.

The vulnerability studies in the Amazon region show some initial advances in understanding the effects of the various types of vulnerabilities on the impact of flood hazards. National hazard-risk studies provide the bases for national indicators. Therefore, some adaptations would be valuable for understanding the complex effects of vulnerabilities in the country. Some specific conditions in the Amazon should be taken into account. Infrastructure vulnerability is the main type of vulnerability that is most relevant in mapping flood-hazard risks.

Flood-risk mapping is a fundamental part of disaster-risk management. It is crucial in information-based decision-making and in providing guidance for defining priorities for risk reduction. In urban areas, the anthropogenic factors that influence or intensify flooding are considered for the minimization or elimination of risk sectors. Demographic and land-use changes have a direct impact on the intensity of floods. All sector risk maps generated by the CPRM have been made available for the civil defense activities of the municipalities, alert centers, ministers, and institutions associated with the National Program for Risk Management and Response to Disasters. This policy is a driver for transformative change that should continue over time.

Author details

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