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Assessing climate change scenarios in the Amazon Basin: a risk governance model

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ABSTRACT

The impacts of climate change are becoming more severe and can only be addressed through governance that spans from local to global levels. To enhance adaptation and response strategies, we need to integrate the knowledge of local communities and improve institutional and state capacity. In the Amazon Basin, current plans for adaptation and response only consider a global perspective, without any input from local communities. By including the region-specific knowledge of these communities, we can better identify the risks related to climate change. The research aimed to answer the question of how to integrate these specificities in an operational risk governance model. We developed an operational risk governance model for Amazon (R-GOMAM) that explores cross-scale interplay and risk identification related to climate change. It provides a comprehensive perspective of risk governance across different scales. A combination of methods was used to integrate the quantitative and qualitative dimensions of data collection and analysis. Additionally, we applied fuzzy logic, to synthesize the cross-scale interplay model. The model was able to account for all dimensions of the Amazon Basin countries, including dryland agriculture, floodplain agriculture, vegetable extraction, fishing, animal breeding, water quality, and household infrastructure. It considered the complexity and uncertainty of risk governance, identified hazard scenarios, and determined the level of risk in the region. Our evaluation of institutional and state capacity in the Purus River Basin revealed insufficient regulations and institutional mechanisms to address climate change risks. Our model identifies different scenarios of hazards and determines the degree of risk in the Amazon Basin countries. Prior models for Brazilian regions overlooked local differences in institutional and state capacities. Our study fills this gap, serving as a supplement for assessing climate change effects in not just Amazonia but other regions as well.

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Amazon; risk governance model; climate change; operational risk governance model for Amazon (R-GOMAM); cross-scale interplay; risk identification

Introduction

Since the end of the twentieth century, discussions about the causes of extreme climate events have become an essential part of our lives, due to the intensity and increase in the related environmental, social, and economic impacts. Such negative impacts continue to result in local and regional vulnerabilities in multiple dimensions: food sovereignty, traditional communities' household income, and fishing in local dimension. In regional level the commodities like soybean production will ultimately translate into regional-scale forest loss in the Amazon, causing the intensity of extreme events. (Assunção, Gandour, and Rocha 2015, Revesz et al. 2014). The International Risk Governance Council (IRGC) highlighted the importance of developing consistent governance at all levels (local, regional, national, and global), to improve the response and adaptation strategies required to address extreme events (International Risk Governance Council (IRGC) 2006). Notably, risk governance is an epistemic branch of risk management that expands the scope of the field towards the involvement of social actors and their knowledge of the spaces in which risk can be identified (Aven 2010, 2012; Aven and Renn 2010; De Marchi and Scolobig 2012; International Risk Governance Council (IRGC) 2006; Marchi 2015; Renn 2008; Renn and Schweizer 2009; Renn et al. 2016; Renn, Klinke, and Van Asselt 2011). However, in the context of the Amazon Basin, only a few studies have explored climate change from a cross-scale perspective. It is confirmed in the literature review that the existing studies concerning the development of specific adaptation plans have mostly been conducted from a global perspective (Berrang-Ford, Ford, and Paterson 2011; Carleton and Hsiang 2016; Corfee-Morlot et al. 2010; Ford and Pearce 2010; Füssel 2007; Lewis and Witham 2012; Revesz et al. 2014; Sun et al. 2022).

The case studies conducted in Brazil on participatory management as a response to climate change highlight the urgent need for development of state and municipal potentialities. In the context of participatory stakeholders in disaster risk governance, the studies reveal that local institutions support the participatory engagement of civil society, but not from a knowledge-based perspective (Bustillos Ardaya, Evers, and Ribbe 2019; Pereira, Barreto, and Pittock 2009). Most of the approaches adopted in these case studies describe such potentialities as participatory community management or collective empowerment when articulated towards risk governance. However, in R-GOMAM, the proposal focused on integrating local participation and institutional assessment.

Notably, the Purus River Basin has one of the most well-conserved biomes in the Amazon; additionally, its population still maintains a vast amount of traditional knowledge, and its local communities have already developed climate change adaptation strategies and techniques (Ravena et al. 2011; Ravena-Cañete 2005, 2010). In the existing literature, most related studies conclude that the municipalities in the Brazilian Amazon are ill-prepared to face the advent of biodiversity and climate change (Bustillos Ardaya, Evers, and Ribbe 2019). Studies have pointed out that adaptive capacity, especially in the municipalities in the state of Amazonas, depends on the state's conditions (at the municipality level) to deal with climate variations (drought and flood) (Malhado et al. 2017).

In this research, we employed the suggested operational risk governance model for Amazonia (R-GOMAM) in the Purus River Basin. This model accurately anticipates climate change risks and aids decision-makers and policymakers in formulating efficient climate change and risk management policies. We employed a mixed-methods research (MMR) approach, blending qualitative data collection and participatory methodologies (field research) with the integration of secondary data in quantitative modelling. The fuzzy inference system (FIS) was used to integrate quantitative and qualitative data into a knowledge base, which can represent a specialist's knowledge *via* fuzzy inference rules. The FIS of R-GOMAM have been developed in MATLAB (The MathWorks, Inc., Natick, Massachusetts) version R2014b (8.4.0.150421), under the license number 990217, with the use of the Fuzzy Logic toolbox.

Data and methods

The cross-scale interplay approach emphasises the interconnectedness of environment and institutions, addressing global collective challenges arising from anthropogenic climate change (Beck 1992; Berkes 2009; De Swaan 1988; Klinke and Renn 2002; Renn 2008; Renn and Schweizer 2009). This strategy is pivotal for robust risk governance model construction, particularly in the intricate Amazon context (Cash et al. 2006; Fleischhauer, Grieving, and Wanczura 2006; Young 2002, 2000, 2006). The R-GOMAM model was developed using an interdisciplinary approach that integrates various factors, including details of the area, institutional dynamics, climate, and hydrological data, to evaluate the impact of climate change. Workshops during field trips helped to foster interdisciplinary communication and incorporate local community knowledge. Fuzzy logic was used in this model to capture the intricacies of climate change. The model uses fuzzy logic to derive institutional capacity and lifestyle data, which were used to inform the risk governance model. In addition, focus groups with local decision-makers were conducted to consolidate information and engage stakeholders.

Climate change impacts are influenced by exposure and vulnerability, necessitating risk governance planning (Aven 2010, 2012; Aven and Renn 2010; De Marchi and Scolobig 2012; Füssel 2007; Renn 2008; Renn, Klinke, and Van Asselt 2011; Renn et al. 2016; Renn and Schweizer 2009). Data on extreme events, civil defence emergencies, vegetation cover, and climate extremes were collected from various sources. These data were integrated with climate change information in the RegCM4 regional climate model, forming the basis for the cross-scale interplay approach in the risk governance model. This methodology involved fuzzy inference system- FIS to model multi-scale data. As suggested by Morgan (2007), a pragmatic approach was taken to integrate qualitative and quantitative data. To achieve a robust integration from a methodological perspective, fuzzy logic and the fuzzy inference system were utilized as tools.

The study covered nine municipalities situated along the Purus River in Brazilian territory, encompassing the States of Acre (AC) and Amazonas (AM). The research team used a middle-draught vessel for navigation, conducting field tasks from Lábrea (AM) to Beruri (AM) and vice versa. To gather infrastructure and socioeconomic data, additional smaller boats called 'voadeiras' were employed to access lakes and igapos during the gap between flood and ebb periods. Data collection in the stretch between Pauini (AM) and Santa Rosa do Purus (AC) was carried out using a single-engine aircraft to reach areas where river depth hindered navigation along the Purus River margins.

Field trips smiddle-draught vessels and smaller boats gathered data on infrastructure, socioeconomic aspects, and local decision-makers' focus groups. Data collection was tailored to the river dynamics, flood and ebb periods, and regional weather conditions. Satellite imaging, scalograms, and downscaling of IPCC forecasts contributed to the necessary information for the R-GOMAM model's.

Framework for the construction of the operational risk governance model for Amazonia (R-GOMAM)

The scales interface, development of a regional climate model, and incorporation of the stakeholders' know-how at the local level were the substantiating strategies for the elaboration of the risk governance model developed in this study. We used fuzzy logic as the artificial intelligence technique for the execution of the above-mentioned approach. The principles of uncertainty and complexity related to the non-linearity of climate change were modelled, using a more elastic gradient of possible actions, for the adaptation and response to this phenomenon, while considering the risks.

The model was based on the meetings held with experts in different knowledge areas (climate, anthropology, agronomy, political science, and economy). After the meetings and joint elaboration of the database analyses resulting from the modelling and field trips, each component was systematised. The methodological framework of the model is shown in [Figure 1](#).

The R-GOMAM framework outlines its components and data collection processes, which are pivotal for data analysis and modeling. This process was applied to create a risk governance model for the Purus sub-basin. Incorporating institutional, socio-economic, climate, and hydrological data, a primary and secondary database was developed ([Figure 1](#)). A conceptual governance model was then constructed to define vulnerability factors and adaptation capacities in the Purus sub-basin, guided by risk governance principles (Aven [2010, 2012](#); Aven and Renn [2010](#); De Marchi and Scolobig [2012](#); International Risk Governance Council (IRGC) [2006, 2017](#); Renn [2008](#); Renn and Schweizer [2009](#); Renn et al. [2016](#); Renn, Klink, and Van Asselt [2011](#)). Workshops with stakeholders in Amazonas and Acre validated the model, involving representatives from municipalities along the Purus River and civil defence officials, and these results were presented to the stakeholders in two workshops for validation ([Figure 2](#)).

The R-GOMAM model utilized the IRGC's risk governance concept (International Risk Governance Council (IRGC) [2006](#)) to develop a theoretical framework for the Purus sub-basin, which expanded risk management to include social and institutional contexts. This approach assessed vulnerabilities and adaptive capacities across regions by integrating hydro-climatic and socio-economic models, state capacity data, and hazard identification. The study employed the model to evaluate risks using Purus River sub-basin data, as shown in [Figure 3](#)'s conceptual model.

The R-GOMAM conceptual model comprises five key groups: hazard identification, vulnerability assessment, potential damage evaluation, institutional and state capacities, adaptive capacity, and risk assessment. This model is the result of the stakeholder's knowledge base, created by integrating with other databases produced by experts through the fuzzy inference system (FIS). It is a comprehensive Risk Governance Model that enables methodological paths to be replicated in different geographical areas and for different risk occurrences. In this case study, the

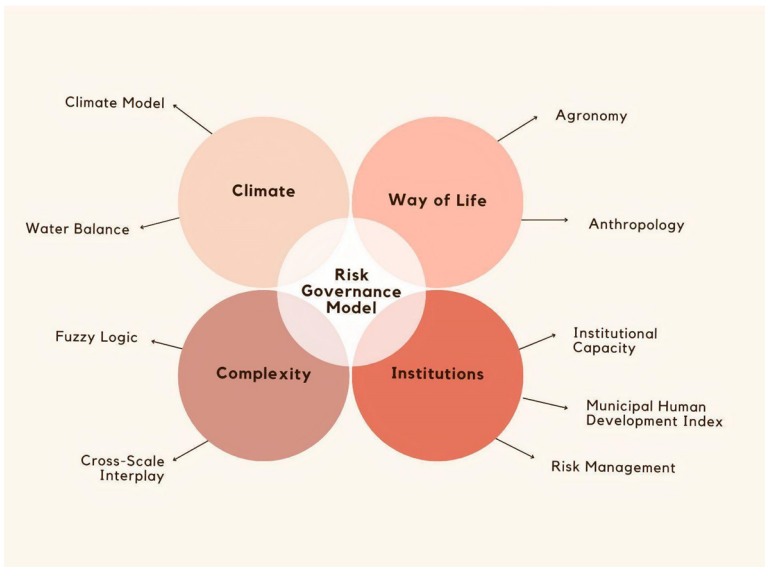


Figure 1. Components interaction framework of the operational risk governance model for Amazonia (R-GOMAM) (Source: the data acquired in this study); municipal human development index (MHDI).

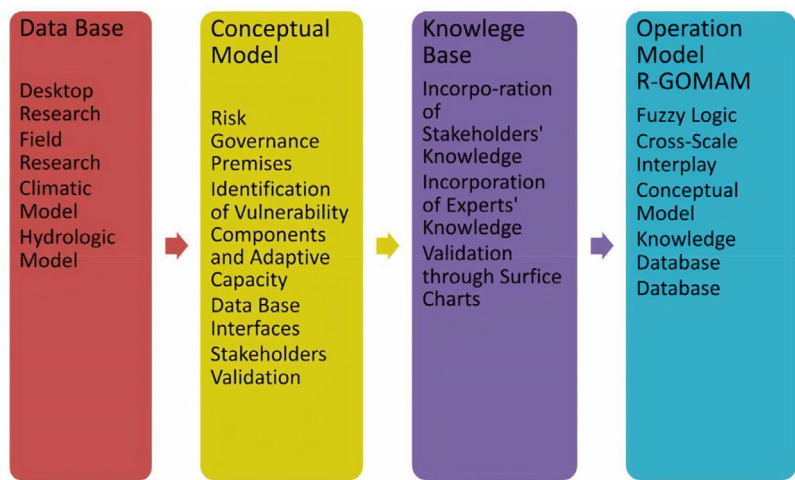


Figure 2. Steps for the construction process of the operational risk governance model for Amazonia (R-GOMAM) for the Purus River transboundary sub-basin (*Source:* this study).

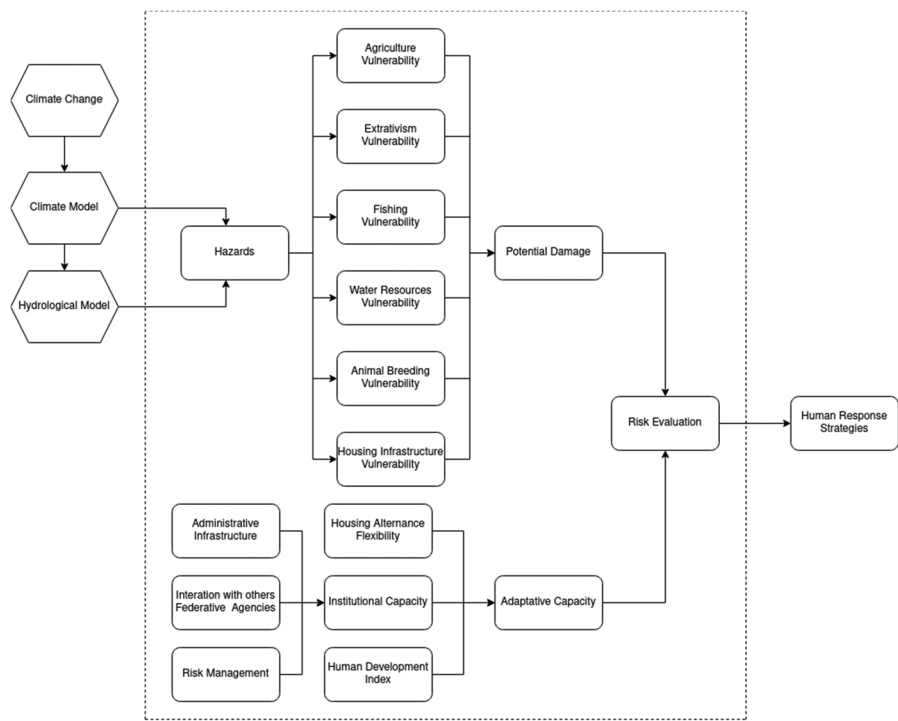


Figure 3. Risk governance conceptual model: Evaluation of climate change impact, adaptive capacity, and response measurement (*Source:* this study).

pragmatic outcomes of this model were demonstrated. Hazard identification employed pluviometric and water-level trends, employing the RegCM4 model to identify extreme events. Vulnerabilities were linked to activities like agriculture, extractive practices, fishing, water resources, animal breeding, and infrastructure. Institutional and adaptive capacities were determined through field surveys, workshops, and secondary data, forming the basis for the R-GOMAM's knowledge-based rules.

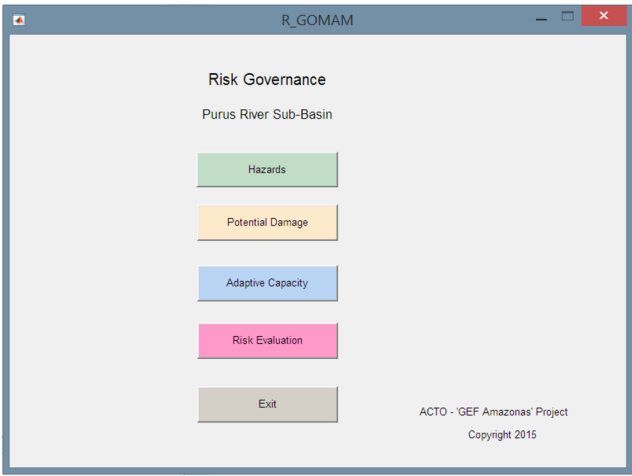


Figure 4. Operation model main screen.

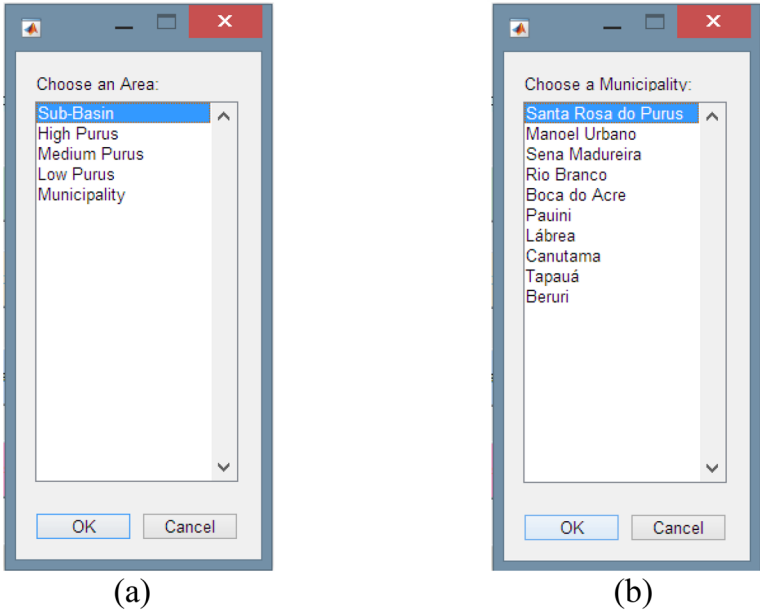


Figure 5. Display option list of the model: (a) options based on geographical areas of the basin and (b) options based on the municipality names.

Fuzzy logic, a computational technique, played a pivotal role in addressing complexity and uncertainty within the model, incorporating human expertise and handling uncertainty. Developed in MATLAB, the R-GOMAM model’s interface enables users to access charts illustrating hazards, impacts, adaptive capacity, and risk assessment across geopolitical regions (Figure 4). It considers various dimensions such as agriculture, extraction, fishing, and housing infrastructure within different risk governance components (Figure 5(a,b)). The model’s application area included municipalities like Santa Rosa do Purus, and others within the Purus hydrographic sub-basins, projecting until 2025 and utilising precipitation, water-level data, and municipal data to determine adaptive capacity through fuzzy inference systems-FIS.

Dimensions of the operational risk governance model for Amazonia (R-GOMAM)

Physical and socio-economic characterization

The Purus River (which extends for 3,700 km from its source in Peru) is one of the largest tributaries of the Solimões River; it has an average discharge of $10,870 \text{ m}^3/\text{s}$ and drains an area of approximately $376,000 \text{ km}^2$, of which 73% is located in the State of Amazonas, 21% in the State of Acre, 5.5% in Peru, and 0.5% in Bolivia (Acre. Secretaria de Estado de Meio Ambiente 2012; Assis et al. 2008; Salimon et al. 2013). Figure 6 portrays the geographic location of the Purus River Basin.

The annual pluviometry of the Purus River Basin presents two well-defined hydrological periods: the rainy (November–March) and dry (May–September) seasons, with the indexes ranging from 1,550 mm to 3,450 mm per year (Silva et al. 2008) (Figure 7). The difference in the water levels of the Purus River Basin between the rainy and dry seasons reached approximately 10 m, whereas, in some parts of the basin, the difference was larger or smaller (Latrubesse et al. 2017, Dos Santos et al. 2018). The entire Amazonas Basin covers approximately one-third of South America ($7,050,000 \text{ km}^2$), considering that the Brazilian part covers about 60% of the entire basin (about half of the national territory) and presents great socio-cultural and biological diversity (Latuf and Amaral 2016; Moran 1990; Tocantins 2000).

The biodiverse Purus River Basin in the Amazon holds local traditional wisdom, enabling adaptive strategies (Diegues 1997, 2002). Climate and river fluctuations shape cultivation of various manioc types and diverse fishing methods matched to local ichthyofauna. A comprehensive grasp of floodplain (várzeas) necessitates further exploration. Moran (1990) suggested including upper, middle, and lower Amazon estuary várzeas in Amazon adaptation discussions. This study adopts Moran's approach, linking várzeas to local life. Upper Amazon Basin várzeas, per Moran (1990), harbour rich biodiversity due to intricate river patterns, leading to unique activities and intensive natural resource use by inhabitants.

The annual activities of the local population directly hinge on the environment, hydrological cycle, and river dynamics. Planting, harvesting, and fishing are aligned with climatic conditions—flooding (October–February), overflow (March–May), ebbing (June–July), and drought (August–September). Categorising the Purus River population solely by socio-economic practices related to natural resources isn't straightforward using Western concepts.

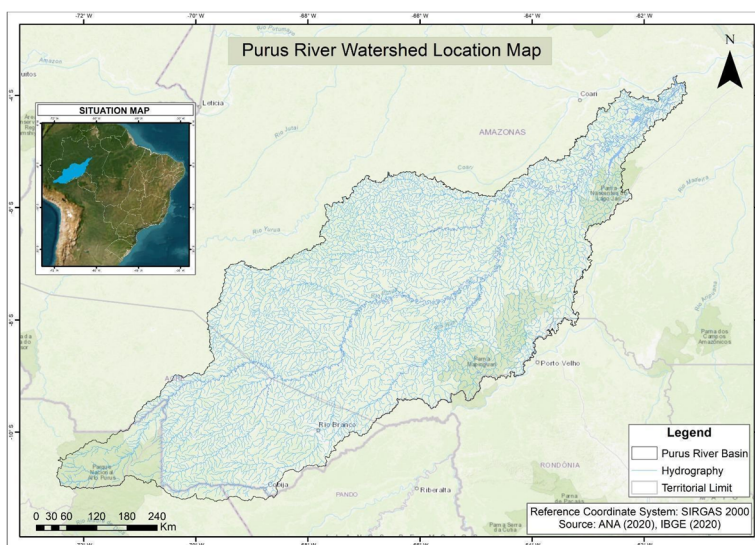


Figure 6. Geographic location of the Purus River Basin (Source: Regional model RegCM4).

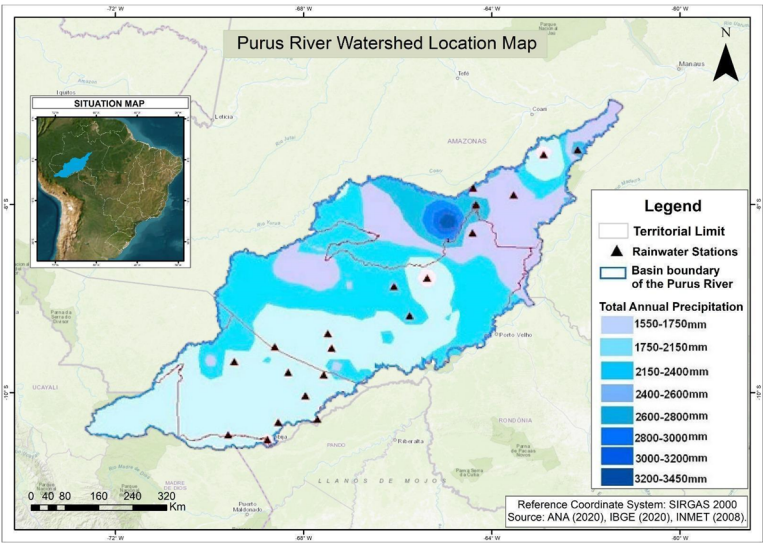


Figure 7. Total annual precipitation in the Purus River Basin (Source: Assis et al. 2008).

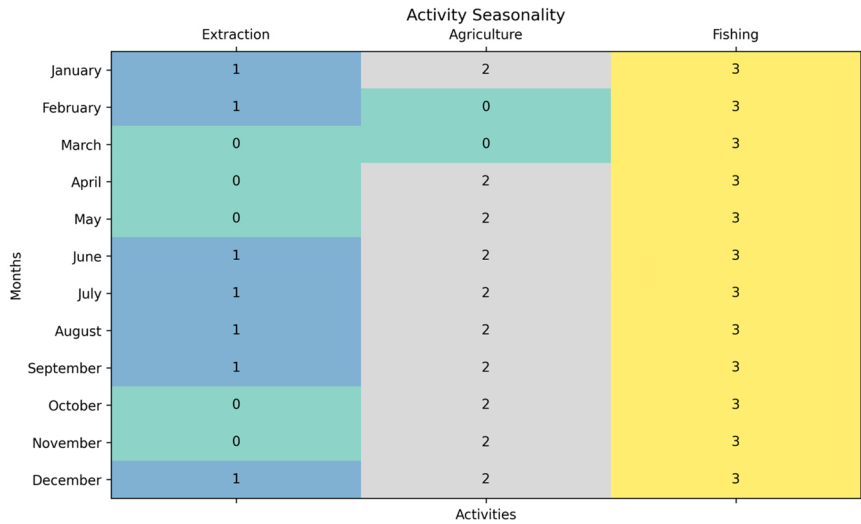


Figure 8. Subsistence activities in the Purus River Basin and the dynamics of the Purus River (Source: Ravena-Cañete et al. 2008).

Daily life revolves around fishing, agriculture, and extractive actions that generate natural resources. Figure 8 offers a succinct overview of these patterns, with numerical values for illustrative purposes representing activity occurrence across seasons. The first column signifies extractive activities (1), the second denotes agricultural activities (2), and the third represents fishing activities (3). An absence of activities is indicated by the value 0.

Amazonian communities primarily rely on fishing, accentuated during ebbing periods when fish abound, backed by literature and field observations (Nepomuceno et al. 2019). Fishing supports year-round subsistence, anchoring men at home, while subsistence agriculture follows. These communities link to the market *via* extractive actions, emphasising fishery and Brazil nuts. Agriculture thrives in várzeas zones, tailored to river levels and rainfall. Enriched by tides,



Figure 9. Illustration portraying the different areas used for cultivation in the Amazon Basin (Source: the authors of this study).

the beach suits minimal-effort small-scale farming ('roça'), involving women. Várzeas, akin to beaches but cleared prior to cultivation, hold denser vegetation. Intermediate zones with river ebb tides ('vazante') support temporary crops by leveraging varied river tides. Permanent crops like banana, mango, and citrus thrive in river ebb tide and várzeas near communities. [Figure 9](#) illustrates cultivation logic based on area choices related to river dynamics.

[Figure 9](#) depicts the influence of river tidal patterns on riverine communities in the Purus River Basin. These communities have developed strategies to cope with extreme climate events, relying on the basin's hydrological dynamics, rainfall patterns, and water cycle. Water's crucial role shapes responses to floods, droughts, river ebbing, and spate events. While historically adaptable, increased event frequency challenges previous approaches. Recognizing changing flood and drought frequencies emphasises the need to adjust to extreme climatic conditions. Economic activities such as farming, animal husbandry, extraction, and fishing align with tide rhythms and define the region's urban and rural communities. Thus, customised strategies account for Amazon Basin nuances in risk governance assessment.

Traditional communities, comprising indigenous groups, riverside inhabitants, fishers, farmers, and extractors, share identities rooted in ethnicity and economic roles. Their evolving relationship with the environment relates to agriculture, hunting, and animal husbandry practices that combat floods and droughts. Tailored to the Purus River Basin, the R-GOMAM model may extend to other sub-basins. The risk governance model integrates socio-economic evaluation, pinpointing key variables for precise risk assessment. Vulnerabilities in agriculture, fishing, extraction, animal husbandry, and water resources were modelled in the tenth conceptual version of the R-GOMAM model using the focus group technique. Urban vulnerabilities and institutional data were sourced from literature reviews and interviews with local bureaucracies and households in Purus River cities.

Institutional and state capacity in risk governance

The R-GOMAM model, utilised in this study, incorporated an institutional perspective to evaluate the impacts of severe climate events on risk governance and water resource management within the Purus River Basin (Nepomuceno et al. 2019). This approach facilitated the development of adaptive strategies and the sustainable utilisation of the basin's natural resources. The study emphasises the importance of understanding the institutional dynamics of municipalities and their relationships within the framework of the Política Nacional de Proteção e Defesa Civil (National Policy of Protection and Civil Defence).

The concept of institutional capacity, which pertains to the ability to perform specific functions, is explored through the lenses of two interconnected theoretical frameworks - state capacity and institutional analysis. Skocpol (1985) defines 'state capacity' as the capacity of federative units to enforce official policies even in the presence of conflicts or economic adversities. Howitt (1977) introduces the concept of 'management capacity,' assessing the degree of autonomy local governments possess in identifying issues, devising policies, and executing programs. Ostrom's work underscores the efficacy of decentralised mechanisms in public service and natural resource management, aligning with the Brazilian National Policy of Protection and Civil Defence (Ostrom, 2014). The study emphasises the challenge of maintaining institutional coherence while accommodating decentralisation and policy fragmentation, especially in the Amazon Basin context. The intricate interplay among state, society, and market shapes state capacity theories, which highlight the role of state autonomy in promoting cooperation and generating public value. The market's influence on vital elements such as nature and work adds complexity, as sectoral interests shape regulatory engagement. Transnational governance further complicates the risk governance challenge in the Amazon Basin, demanding a nuanced comprehension of interactions between local and global institutions.

In remote areas such as Amazon Basin municipalities, the impacts of climate change and sectoral interests are internalised. The capture of risk governance by political forces during extreme climate events highlights failures in municipal-level state capacity. Responses often focus on social compensatory strategies for electoral gains, revealing a disconnect between state capacity and local realities. The implementation of the Brazilian National Policy of Protection and Civil Defence exacerbates federative imbalances due to its centralised nature, which doesn't align with the diverse needs of regions like the Purus River Basin.

The Brazilian National Policy of Protection and Civil Defence's centralised approach lacks adaptability to regional variations, rendering it ineffective. Field trips highlight political bias in the Purus River Basin, exposing policy misalignment. Extreme events reveal policy inadequacy and municipal vulnerability. Riverine communities develop coping strategies, sharing insights through workshops and interviews for institutional diagnosis. Workshops and interviews shape R-GOMAM's institutional aspects, adopting a cross-scale and polycentric approach, enhancing stakeholder engagement. This comprehensive method leads to effective public policy formulation.

Water and climate dimension in the risk governance in the Amazon Basin

Since the late twentieth century, a global dilemma has revolved around discussing the genesis, characteristics, and impacts of climate change across different regions. Extreme climate events gain significance in societies due to their frequency, intensity, socio-environmental vulnerability, and public understanding (Etkin and Ho 2007; Hoogendoorn, Sütterlin, and Siegrist 2020; Juanchich and Sirota 2016).

Rising temperatures are considered the primary driver for extreme alterations in precipitation rates and atmospheric variables, affecting water availability in water basins through runoff and soil recharge (Diodato et al. 2020; Markonis et al. 2019; Scharadong, Simonovic, and Garcia 2014). Climate alterations are susceptible to climate change (Marin et al. 2020). Specific geographic and sectoral contexts modify vulnerability levels; regions experiencing intensified extreme events due to climate change see elevated economic costs, particularly in directly impacted areas (Marengo 2009; Marengo et al. 2016; Marin et al. 2020). The Amazon Basin plays a vital role in the global carbon balance, capturing atmospheric carbon and significantly contributing to the world's forest sector (Gatti et al. 2021; Grace 2016; Nagy, Artaxo, and Forsberg 2016).

The Amazon forest's real contribution to global climate is under scientific investigation, revealing its vital role in regulating rainfall and water cycles across South America and beyond.

These processes are influenced by practices such as deforestation, gas emissions, and controlled land clearing through fire (Aragão and Shimabukuro 2010; Campanharo et al. 2019; Lemos and Cunha 2021). The Amazon region may suffer significant environmental impacts due to climate change, driven by increased greenhouse gas concentrations (Le Page et al. 2012). The Amazon forest significantly affects the South American climate by regulating regional water cycles and humidity. Trade winds from the tropical Atlantic carry humidity to the Amazon region, and after rainfall, the forest's intense evaporation recycles humidity, returning much of it as rainfall (Aragão et al. 2018). Estimates indicate that 30–50% of the Amazon basin's pluviometric precipitation is recycled evaporation (Fisch, Marengo, and Nobre 1998). Furthermore, the generated humidity in the Amazon Basin is carried by winds to other parts of the continent, contributing to precipitation in distant regions as well (Dos Santos et al. 2018; Marengo et al. 2011, 2016; Weng et al. 2018).

Sophisticated models, while advanced, have constraints in capturing the intricate physical processes and interactions of the climate system, particularly in nonlinear scenarios and across different time spans. The integration of social and institutional aspects into climate models adds another layer of complexity, shaping decisions in climate risk governance (Grigoroudis and Petridis 2019; Papadelis and Flamos 2019). To tackle this uncertainty, the R-GOMAM model employed fuzzy logic to examine the interplay between climate, lifestyle, and institutions in the Amazon Basin, thereby enhancing the utility of climate forecasts.

The study employed the RegCM4 regional climate model, continually improved by the International Centre for Theoretical Physics (ICTP) in Italy (<http://gforge.ictp.it/gf/project/regcm/>). RegCM4, a limited-area community model, employs sigma-p vertical coordinates and a horizontal Arakawa B-grid, built on primitive equations for fluid dynamics (Dickinson et al. 1989; Giorgi and Bates 1989; Pal et al. 2007).

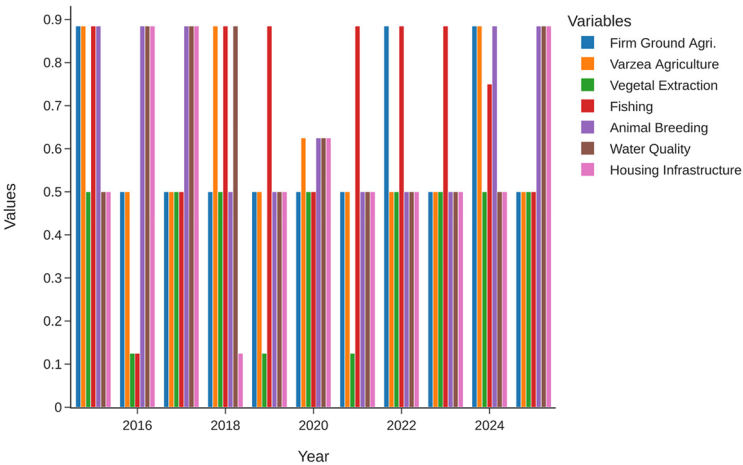
Discussion and results

In Figure 10, we display the risk evaluation results for Santa Rosa do Purus (Figure 10(a)), Pauini (Figure 10(b)), and Beruri (Figure 10(c)). These figures offer a comprehensive perspective on risks across all R-GOMAM dimensions (physical, socioeconomic, institutional, and climate) from 2015 to 2025. This analysis takes into account precipitation and water-level forecasts for the Purus River basin, using data from the RegCM4 Climate Model.

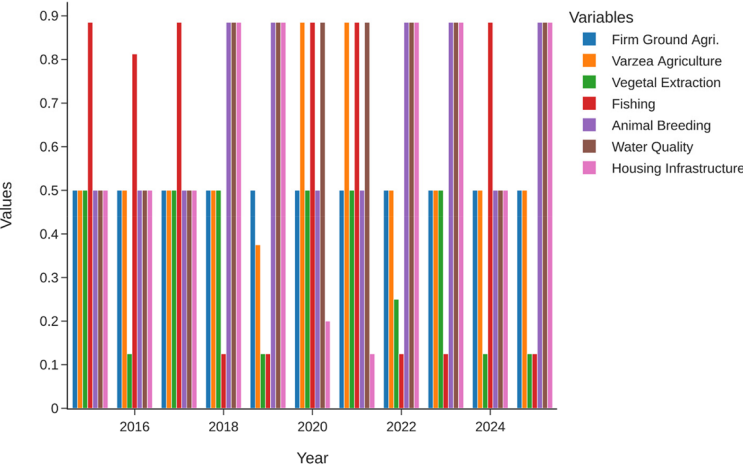
If a user, as a bureaucrat policymaker from the national or transnational policy level, chooses to view the risks of all the cities of the Purus River Basin, all municipalities are shown in a chart in the same format as those seen in Figure 10, with different results. Alternatively, it is possible to generate only the municipalities of a region or a single municipality, according to the option selected by the user.

The institutional component

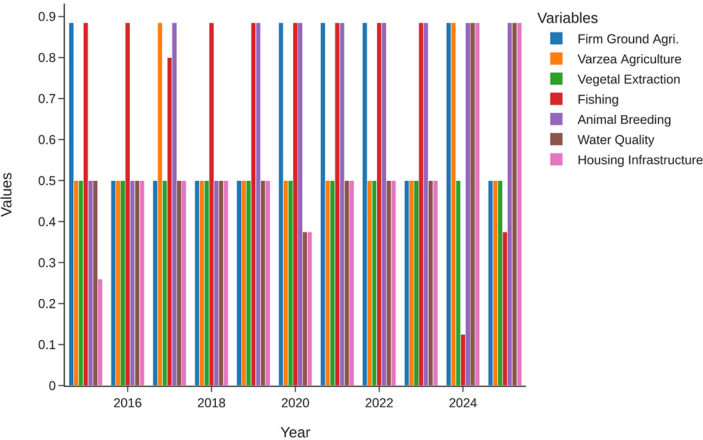
The assessment of the institutional and state capacity of the municipalities along the Purus River Basin in governmental bodies, based on the analysis of the municipal infrastructures and local policies, institutional arrangements for the management and legislation of water resources, and organizational structures of the city master plans as a starting point for the implementation of adaptation strategies to climate change in risk governance scenario, indicated that regulatory provisions and institutional mechanisms currently in place in the states of Amazonas and Acre that cover the Purus River Basin are insufficient to encompass the specificities of the risks related to climate change in the region. Thus, it is important to adopt a governance model, along with the direct participation of stakeholders, in the implementation of effective response measures during extreme events. Considering the Purus River Basin as a paradigmatic Amazon area, the



(a)



(b)



(c)

Figure 10. Charts of the risks observed in the Purus River Basin municipalities. Visualization of the risks for the (a) Santa Rosa do Purus municipality, located in the Upper Purus region; (b) Pauini municipality, located in the Middle Purus region; (c) Beruri municipality, located in the lower Purus region.

R_GOMAM model (as a risk governance model) was developed to fulfil the institutional dimension gaps in the previous risk models used to design the Brazilian National Policy of Protection and Civil Defence – PNDEC.

The climate component

According to the precipitation data obtained for the up, middle, and lower Purus River, the main conclusions extracted from the study reveal that the precipitation simulated by the RegCM4 model portrayed good qualitative results at a monthly scale (seasonality) and good quantitative results at an annual scale. In the trend analysis of the simulated precipitation data, an increasing trend was observed in the precipitation events, within the average of the observational data. The results obtained by the model estimated the water level during the flood and ebb phases of the river.

Aligned simulations of regional atmospheric models demonstrated their accuracy in estimating precipitation at a water basin scale. Upon data rectification, these models closely approximated observed rainfall in the basin, subsequently enhancing water level estimation within the study area's basins. The performance of precipitation simulation and forecast, driven by regional climate dynamic modelling, can enhance the management of surface water utilisation in extensive water basins by providing improved intra-seasonal scale data for hydrologic models.

The study's conclusions from the analysis of the up, middle, and lower Purus Rivers are as follows:

- The RegCM4 model accurately simulated precipitation on a monthly scale, showcasing good qualitative seasonality and robust quantitative annual results.
- Overall, the trend analysis of simulated precipitation data revealed a consistent increasing trend in precipitation events, aligning with observational data averages.
- Nash analysis results indicated high acceptance, with deviations between simulated and observed data exceeding 80%.
- Generally, the model underestimated water levels during the river's flood and ebb phases.
- Despite being simulations, the study suggested that aligned regional atmospheric models can accurately estimate basin-scale precipitation. Upon data rectification, these models closely approximated observed rainfall, thereby enhancing water level estimation in the study area's basins.

This suggests that the performance of the precipitation simulation/forecast resulting from the regional climate dynamic modelling, used as the entry data in hydrologic models of rainfall and water level at an intra-seasonal scale, can be used to improve the management of surface water use in large water basins. Thus, the impacts of the hydrologic model associated with the institutional analysis and the description of the social group's way of life were clearly understood in the workshops. The stakeholders validated the climate model and its forecasts as a component of the R-GOMAM model, along with the result of the analysis. Furthermore, the ways of integrating the components were presented to the stakeholders, and with their participation, we developed the knowledge base of the R-GOMAM model. The stakeholders validated the climate model and its forecasts as a component of the R-GOMAM model, along with the analysis result. Furthermore, the ways of integrating the elements were presented to the stakeholders, and with their participation, we developed the knowledge base of the R-GOMAM model.

Conclusions

The R-GOMAM model is a valuable tool for analysing climate-change-related risks and aiding decision-making. It specifically focuses on assessing risks in the Amazon Basin, a region often underexplored in this context. The model consists of three dimensions: climate change data over a decade, vulnerable human activities, and local institutional capacities to manage impacts.

Given the Amazon Basin's complexity, political decisions must consider its intricacies. R-GOMAM serves as a comprehensive tool capturing risk governance's complexity and uncertainty. It can simulate various hazard scenarios and associated risk levels for Amazon Basin countries. Developed in 2014, it highlighted a lack of local response during a 2015 flood due to governance deficiencies. The model also evaluates institutional and state capacities, offered to the Brazilian Civil Defense National Secretary.

The absence of R-GOMAM adoption in Brazilian climate change and risk governance agencies poses issues during Amazon's critical events. External influences standardized adaptation measures across Brazil. Other Brazilian regions' response models often ignore regional variations in state and institutional capacities. R-GOMAM's integration of methodologies and local knowledge distinguishes it in risk sector policies.

Despite its limitations, the R-GOMAM model extends beyond its immediate scope. It serves as a framework for future studies, potentially influencing vulnerability analyses in diverse regions. By adapting R-GOMAM principles, researchers can enhance global risk governance and adaptation strategies.

Furthermore, R-GOMAM evaluates risk governance effectively through cross-scale interplay and fuzzy logic. It combines physical risk characteristics with political policies across scales, addressing global collective risk challenges. Its institutional and state capacity dimensions reduce operational barriers, enhancing adaptability to climate change. Notably, the R-GOMAM model's significance extends to its governance dimension. Decision-makers' consensus adoption could apply this model to Amazon sub-basin rivers, including transboundary areas.

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