Climate-Associated Natural Disasters in the Sub - Hydrographic Basin of the Banabuiú River, CE, Brazil

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ABSTRACT : *Natural disasters have become more frequent in recent decades. This increase is a consequence of intense natural events added to the precarious social and economic contexts of the territories, which cause severe impacts on the population. Climate-related disasters, such as droughts and floods, are the most frequent and intense in northeastern Brazil. The present research analyzes the spatio-temporal distribution of natural disasters related to climate dynamics and determines the social vulnerability levels of the municipalities that comprise the Banabuiú River sub-basin. The methodological procedures of the research were: bibliographic survey, data harvesting on natural disasters from 2003 to 2020, selection of vulnerability indicators, calculation of the vulnerability index, and results' spatialization. The results reveal that the region under analysis is most affected by droughts, responsible for 86.7% of disasters. The social vulnerability study of the sub-basin identified the municipality of Itatira as the most vulnerable. On the other hand, Limoeiro do Norte and Quixadá have the slightest vulnerability. The results can contribute to risk management policies and integrated sectoral policies to minimize vulnerability and risks to natural disasters.*

KEYWORDS –*Dry, Hydrographic basin, Inundation, Natural disaster, Vulnerability.*

I. Introduction

Natural disasters are a problem that is increasingly present in people's daily lives, regardless of whether or not they live in at-risk areas. In fact, over the last few decades, the recurrence of disasters and the magnitude of the damages they cause have been increasing worldwide (Tominaga; Santoro; Amaral, 2009). Some of these extreme events are associated with climate and meteorological conditions (Marengo *et al.*, 2020), which are related to climate change, as shown by global projections (IPCC, 2021).

Disasters can occur naturally or due to human actions but always cause material damage and social, economic, or environmental losses. Therefore, they are sources of risk to exposed people and places (Gallina *et al.*, 2016). In Brazil, since the 1960s, there has been a significant increase in recorded natural disasters. This increase is a consequence of several factors, for example, the intense cities expansion in areas unsuitable for occupation due to unfavorable environmental characteristics (Tominaga; Santoro; Amaral, 2009).

These environmental changes exacerbate pre-existing risks and create new ones, which may become disasters in various situations (Nunes, 2015). According to the World Bank (2020), between 1995 and 2019, Brazil issued around 64,429 records of natural disasters. The study also highlighted those disasters caused losses of R$333.36 billion. Climatological events are responsible for 60.32% of these disasters. The Brazilian

Northeast region concentrates the largest amount of losses (42.17%) and disaster records (46.15%) (World Bank, 2020).

The semi-arid climate domain of the Northeast region has a high degree of precipitation variability, potentially aggravated by climate change (Marengo *et al*., 2016). Drought and flood events are mainly responsible for the declaration of an Emergency Situation (ES) [1]or State of Public Calamity (SPC) in the region (Olímpio, 2017), causing significant damage and losses, including human lives (Moura *et al*., 2016). Although droughts and floods are characteristic phenomena of the semi-arid region, the region still lacks investments to reduce disaster risks that allow for a reduction in vulnerability levels and coexistence consistent with regional climate dynamics (Olímpio, 2013, 2017).

These conditions are present in the Banabuiú River sub-basin. The selection of this study area is justified by inequalities in living conditions and access to essential services and infrastructure, resulting in deprived areas. As Duarte (2009) points out, unequal conditions and socio-spatial segregation of socio-environmental vulnerabilities distinctly expose population groups to risks. The present research analyzes the spatiotemporal distribution of natural disasters related to climate dynamics and determines the levels of social vulnerability of the municipalities that make up the Banabuiú River sub-basin. These research results can support discussions on managing risks related to droughts and floods in the study area.

II. Theoretical Reference

In recent years, studies on risk analysis have grown in different areas of knowledge, each with different approaches and methods (Marandola Jr; Hogan, 2004; Olímpio, 2017). According to Dagnino and Carpi Jr. (2007, p. 52), the word risk is often "replaced or associated with potential, susceptibility, vulnerability, sensitivity or potential damage."

In postmodern society, risk is inherent to life itself, appearing in each individual's daily activities. Therefore, it is expressed in a growing feeling of unrest throughout society (Olímpio, 2017; Teles, 2001). In the current context of modernity, risk is "A situation with an uncertain future and the probability that a harmful event will affect a population or its vulnerable material and immaterial assets, causing damage and losses" (Olimpio, 2013, p. 31). Teles (2001) adds that the impacts caused are felt and perceived differently by populations, depending on the temporal, social, economic, cultural, and demographic dimensions in each portion of the geographic space.

Sousa *et al.* (2020) corroborate this argument by expressing that risk refers to the probability of profound implications such as damage or loss occurring and resulting from the interaction between a hazard (natural, technological, or social) and a condition of vulnerability. In this sense, when it comes to risk, "the danger and vulnerability (population density, infrastructure, poverty, etc.) of the system that is about to be impacted must be considered" (kobiyama*et a*., 2006, p. 17).

In the case of natural hazards, it is understood that these phenomena may occur at different times and in different regions (Tominaga; Santoro; Amaral, 2009). According to Olímpio and Zanella (2017), hazards refer to a situation in which a harmful event or a set of associated events may occur in more or less known regions and periods. Therefore, according to these authors, to delimit risk areas and implement risk mitigation measures, it is mandatory to identify spaces and people exposed to the potential impacts of a severe natural event.

The vulnerability concept is central to understanding this issue in studies on environmental risk and climate change. Vulnerability is a very diffuse term with several definitions used in different disciplinary contexts. Still, they all describe a situation of fragility concerning a specific danger or set of hazards (Zanella*et al*., 2009).

[1]The ES is the legal recognition by the public authorities of an abnormal situation caused by a disaster that causes damage and losses that imply the partial impairment of the Public Power's response capacity (Brazil, 2020). In the SPC, damages and losses imply a substantial compromise in the Public Power's ability to respond. In other words, the impacts are more severe.

Therefore, studies on risks point out a tendency for the most vulnerable populations to concentrate in at-risk areas that do not have adequate resources to resist the impacts of dangerous natural events (Veras, 2010; Deschamps, 2008). The very insufficiency of infrastructure and services is an indicator of populations exposed to environmental risks (Zanella, *et al*., 2009).

Marandola and Hogan (2004) associate vulnerability with the notion of response capacity, adjustments, and absorption of impacts. The authors claim that those who have better infrastructure conditions and access to basic services such as public sanitation or public health services also have a better capacity to deal with their losses, save their lives, and adapt to the effects of extreme environmental fluctuations.

According to Veyret and Richemond (2007), vulnerability derives from the scarcity of resources in the face of a crisis and the precariousness of infrastructure services. Therefore, vulnerability occurs depending on the living conditions of a population, estimated by factors such as the lack of sanitation and the housing situation. This way, it is possible to measure it, as the areas differ based on the effects generated by the same extreme event (Silva; Santos, 2012).

In fact, natural disasters and associated impacts, especially those triggered by intense atmospheric events, have increased in several parts of the world (Marcelino*et al.*, 2006). The concept of disaster considers the materialization of damage to society, exposing the magnitude of an event and its relationship with the affected environment's vulnerability (Olímpio, 2017). According to Nunes (2015), a disaster is an intense change in territorial functionality. The author also states that the negative impacts may be more related to how space is used and occupied by society than to the magnitude of the phenomenon. In agreement with the author, Tominaga *et al.* (2009) explain that the lack of planning and management has intensified disasters.

Current climate variability and the increase in global temperature are associated with an increase in climate extremes (Marengo*et al*., 2020). Climate phenomena such as droughts and torrential rains, among others, may become more frequent, increasing the possibility of natural disasters (Tominaga; Santoro; Amaral, 2009; Moura *et al*., 2016).

According to Marengo *et al.* (2016), droughts are natural phenomena derived from hydrometeorological regime changes. According to Silva *et al*., (2013) and Campos and Studart (2001), drought is a climatic phenomenon occurring when precipitation in a given period and location occurs with lower incidence than the usual values. In addition to the natural conditions, the social and economic contexts together can induce the occurrence of disasters, as the population does not have the necessary infrastructure to cope with periods of water scarcity.(Melo*et al*., 2009). The main effects of droughts are water shortages in cities, compromised water quality, limitations in industrial production, and the crops and livestock loss.

However, the same regions affected by droughts may also be susceptible to episodes of severe rain, which disrupt territories through flooding. According to the National Secretariat of Civil Defense (Brazil, 2007), floods derive from large amounts of waternot absorbed by the soil, rivers, or other forms of drainage, causing the overflow of river beds, lakes, canals, and dammed areas and adjacent land, causing affecting the resident population and infrastructure, besides to the services functioning.

For Nunes (2015), when the volume of rainfall is greater than the absorption capacity of the surface, floods can cause dam failures and economic losses, generate food insecurity, favor the proliferation of diseases, make agricultural practices impossible, and cause deaths. The occupation of naturally susceptible environments aggravates this situation when the soil is impermeable or insufficient drainage infrastructure.

III. Material and Method

Study area

The Banabuiú River sub-basin is located in the semi-arid region of Ceará in Brazil (Fig.1), occupying the state's central portion. The drained area is 19,316 km² (a surface corresponding to the extension of theState of Israel), corresponding to 13.4% of the state of Ceará. The sub-basin completely drains the municipalities of

Banabuiú, Boa Viagem, Madalena, Mombaça, Pedra Branca, Piquet Carneiro,Quixeramobim, and Senador Pompeu. The sub-basin also partially drains the municipalities of Ibicuitinga, Itatira, Limoeiro do Norte, Milhã, Monsenhor Tabosa, MoradaNova, and Quixadá. It is worth mentioning that some of the municipalities of Ibaretama, Jaguaretama, and Santa Quitéria are also in the basin.However, these areas do not have municipal or district headquarters; therefore, they are without a significant population quantity. The resident population [2]comprised 545,257 individuals. According to thelast demographic census, 56.9% lived in urban areas (Brazil, 2010).

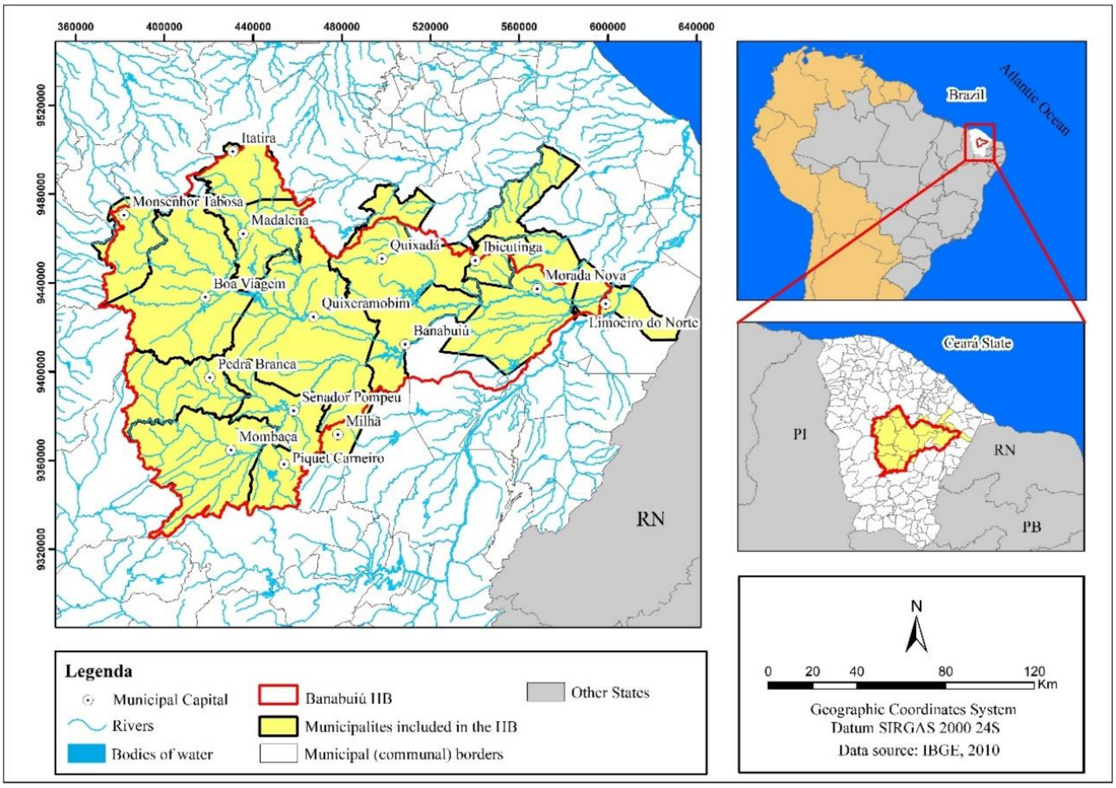

Figure 1. Location map of the Banabuiú river sub-basin. Source: authors.

The drainage network flows mainly in a west/east direction, with the main tributaries being the Patu, Quixeramobim, and Sitiá rivers and the Livramento stream. The Banabuiú River is the main tributary of the Jaguaribe River, the largest river basin in Ceará (Ceará, 2020).

Due to the integrated water storage and distribution system between the state's river basins, the Banabuiú river sub-basin is strategic to supply rural populations and those residing in the metropolitan region of Fortaleza. The basin can store 2,760,549,943 billion m³, distributed across 19 public reservoirs (Ceará, 2020).

The study area is in the Brazilian semi-arid climate domain, characterized by high annual temperatures, strong evaporation rate, low cloud cover, high insolation, and significant temporal and spatial rainfall irregularity (Costa et al., *2016*; Zanella, 2014; Santos, 2021).

This rainfall variability produces drought maximums, sometimes generating catastrophic droughts and extreme rains, causing contingent floods. In recent years, the reservoirs in this basin have suffered continuous

[2]This information considers the total population of the municipalities, even those that only contain part of the territory within the sub-basin under study.

losses in water stocks due to consecutive dry years, so populations have been coping with water scarcity (Ceará, 2020).

It is noteworthy that precipitation is concentrated between February and May, with the Intertropical Convergence Zone (ITCZ) being the main precipitation-inducing system (Marengo, 2008; Zanella, 2014). However, the atmospheric circulation mechanisms associated with the El Niño-Southern Oscillation (ENSO) phenomena, the Atlantic Dipole, and the Madden-Julian Oscillation condition the systems' performance in the study area (Ferreira; Mello, 2003; Olímpio, 2017).

IV. Method

The research followed the steps: 1) Bibliographic review; 2) Collection of data on climate-related disasters; 3) Selection and collection of vulnerability indicators; 4) Calculation of the Social Vulnerability Index; and 5) Cartographic material production.

Initially, a bibliographical review explored the discussions about the issues investigated, focusing on studies of risks and vulnerabilities (Rosa and Costa, 2009; Costa and Marguti, 2015; Olímpio, Zanella and Santos, 2017), climate-related disasters (Olímpio, 2017; Moura *et al*., 2016) and rainfall variability in the Brazilian semi-arid region (Marengo, 2008; Zanella, 2014).

In the second stage, consultations were carried out on the historical series of Ordinances recognizing Emergency Situations (ES) and State of Public Calamity (SPC) caused by natural events impacting water scarcity and hydrometeorology. The National Secretariat of Civil Defense had provided these data on the period between 2003 and 2020 when there was no systematized data in the Integrated Disaster Information System (S2ID). It was decided to count episodes of drought and dry periods as events that induce water scarcity and episodes of floods, intense rains, and flash floods as floods, as carried out in other research (Olímpio; Zanella, 2015, Moura et al., 2016; Nascimento, 2023).

Subsequently, the study created a Social Vulnerability Index (SVI) according to Rosa and Costa's (2009) method. Thus, four dimensions were selected to measure social vulnerability: education, employment, income, family arrangement and infrastructure, and basic services. These dimensions were composed of nine indicators (Table 1). The selection of these indicators considered their relevance, intensifying the vulnerability levels of populations to climate extremes, data availability, and their use in previous studies.

Dimension	Indicator
Education	I-1. Illiterate men responsible for households.
	I-2. Non-literate women responsible for households.
Employment and Income	I-3. Men responsible for households with no nominal monthly income.
	I-4. Women responsible for households without income.
Family Arrangement	I-5. Men with a nominal monthly income of up to 2 minimum wages are responsible for households.
	I-6. Women with nominal monthly income of up to 2 minimum wages responsible for households.
Infrastructure and Basic Services	I-7. Households that do not have garbage collected by cleaning services or dumpsters.
	I-8. Households that do not have a bathroom or toilet connected to the general sewage network or septic tank.
	I-9. Households that are not connected to the general water supply network.

Table 1 Social vulnerability indicators. Source: authors.

Data were collected from municipalities, wholly or partially, within the Banabuiú river basin. The data derive from the last demographic census, carried out in 2010 and provided by the Brazilian Institute of Geography and Statistics (IBGE) (Brazil, 2023).

Then, the data was normalized, considering that each indicator has different scales and magnitudes. To this end, (1) was applied.

$$I_n = \frac{I_{(x)} - Min_{(x)}}{Max_{(x)} - Min_{(x)}} \tag{1}$$

Where: I_n = standardized value of indicator "I" in municipality "s"; $I_{(x)}$ = value of indicator "I" in municipality "s"; $Min_{(x)}$ = lowest value of indicator "I" in the universe of municipalities, and; $Max_{(x)}$ = highest value of indicator "I" in the municipalities universe. The equation returns values between zero and one, and the closer to one, the greater the vulnerability (Rosa and Costa, 2009; Olímpio, Zanella, and Santos, 2017).

Weights were assigned to each indicator based on proposals from other studies (Rosa and Costa, 2009; Olímpio, 2013) (Table 2). For the education and income dimensions, the indicators representing families headed by men were less vulnerable and received weight 1, while when women ran them, they received weight 2. This methodological choice is justified because several studies demonstrate that women have lower incomes and more difficulty accessing the best jobs in Brazil (Rocha *et al*., 2017). For example, in 2010, women's monthly income corresponded to only 58.1% of men's income (Brazil, 2023).

Education	Employment and income	Family arrangement	Infrastructure
I- 1 I- 2	I- 3 I- 4	I- 5 I- 6	I- 7 I- 8 I- 9
1 2	1 2	1 2	1 2 3

Table 2 Weighting of social vulnerability indicators. Source: adapted from Rosa and Costa (2009).

Infrastructure and basic services supply indicators were used because their lower presence may indicate the location of more economically vulnerable populations residing in more unhealthy housing and environmental conditions. Families' choice of these locations is driven by socioeconomic conditions (land and housing prices) and proximity to amenities (workplace, schools) (Winsemius*et al*., 2018).

The indicator of tap water access received a weight of 3 because it is an essential condition for life. Meanwhile, the sanitary sewage indicator received a weight of 2 because its absence is strongly related to conditions producing unsanitary environmental conditions and the spread of diseases. Finally, the garbage collection service indicator weighs one because it is a service with the most significant reach to the population.

Then, the weighted average of each dimension was calculated. Equation 1 was applied again to normalize the values and generate the Social Vulnerability Index (SVI). The values obtained were ordered and grouped using the "*natural breaks" (*Jenks, 1977)method into five vulnerability classes: very low, low, medium, high and very high. Census data were tabulated and organized using *Microsoft Excel software*.Finally, to produce the cartographic material, the *softwareArcGIS 10.5*.

V. Results and discussion

From 2003 to 2020, the municipalities in the Banabuiú basin received 234 ES or SPC Recognition Ordinances (Fig.2). Two hundred and eight were due to natural events associated with water scarcity and floods triggered 26.

However, the interannual and intra-annual variability of precipitation is responsible for the scenarios observed throughout the investigated period. Fig.3 shows the temporal distribution of ordinances registered in the Banabuiú river basin. All the analyzed years presented drought-related crises, the hardest between 2006-2007 and 2012-2017, when all municipalities were severely affected. The flood episodes occurred in three years, with emphasis on the years 2004 and 2009. Fig.4 shows the spatiotemporal distribution of disasters in the study area.

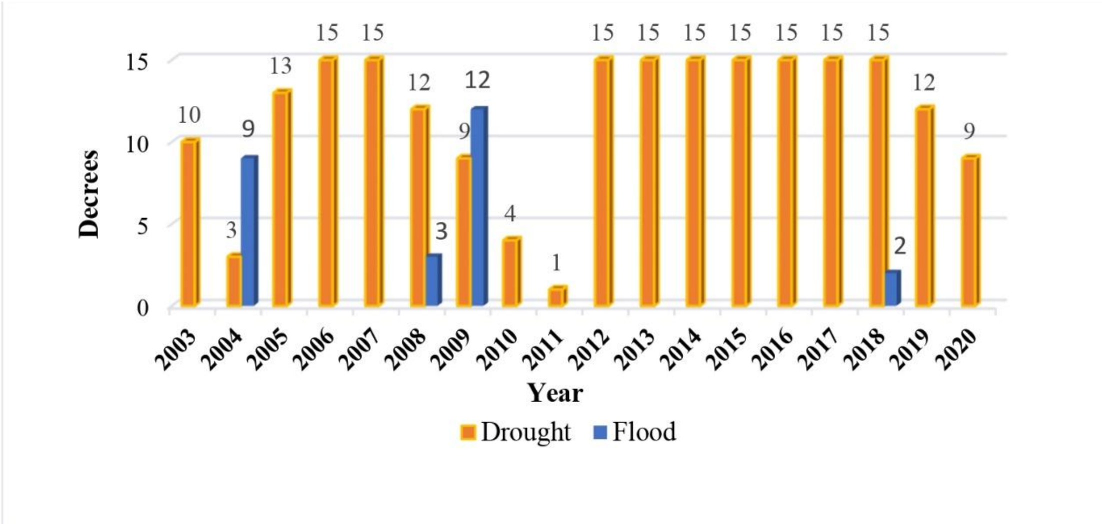

Figure 2. Temporal distribution of ESs and SPCs Recognition Ordinances (2003-2016). Source: authors.

Spatio-temporal distribution of drought disasters

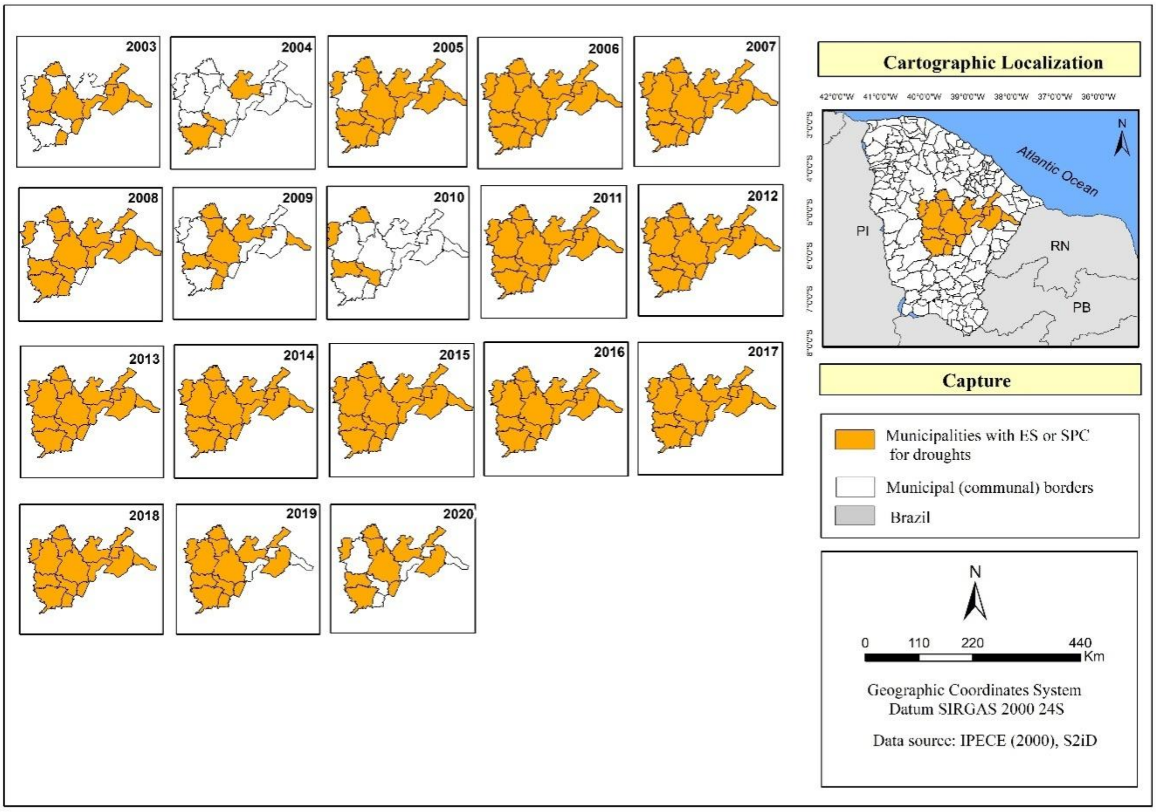

Figure 3. Spatial and temporal distribution of ESs and SCPs for droughts. Source: authors.

In 2003, 10 municipalities out of 14 recorded crises caused by droughts. Olímpio and Zanella (2015) observed that this year's water crises were concentrated in the central portion of the state of Ceará, where the Banabuiú basin is located. However, Silva (2023) classified the 2003 rainfall in the Banabuiú sub-basin as rainy. Such impacts are due to the irregularity of precipitation between the months of the rainy season.

In 2004, only three municipalities suffered severe losses due to water shortage since the neutral conditions of ENSO and the Atlantic Dipole induced rainier conditions (Olímpio; Zanella, 2015).

Between 2005 and 2007, 43 decrees were recognized, caused by losses associated with reduced volumes stored in reservoirs throughout the sub-basin. In those years, oceanic-atmospheric conditions were unfavorable for regular rainfall of sufficient intensity to replenish water reserves. In this scenario, the drought may not generate significant impacts at first, but its persistence causes severe crises in social, economic, and environmental stability (Olímpio, 2017).

The years 2008 and 2009 were considered rainy and very rainy, respectively (Silva, 2023). However, rainfall did not generate sufficient water reserves, given the low volumes stored in previous years (Olímpio; Zanella, 2015).

In 2010, an intense El Niño episode favored the occurrence of a dry year in the state of Ceará, but with more intense effects in the North and Center-South regions (Olímpio, Zanella, 2015). Silva (2023) classified this year as dry in the Banabuiú sub-basin. However, the impacts were less severe than in previous dry years due to water reserves from 2009.

The year 2011 presented a rainy condition (Silva, 2023): only the municipality of Mombaça received recognition of its crisis due to water shortage. However, Cortez, Lima, and Sakamoto (2017) emphasize that the distribution of precipitation was not favorable to the reservoirs' water supply.

From 2012 onwards until 2017, a prolonged drought began in the study area. The reduction in water reserves and agricultural losses led to the declaration of disasters in all municipalities in the sub-basin and all years, totaling 90 records.

2012 was considered extremely dry, 2015 was very dry, 2014, 2016, and 2017 were dry, and 2013 was normal (Silva, 2023). As a result, all municipalities in all years obtained recognition of emergency declarations. The years 2018 and 2019 were classified as normal. However, the irregular precipitation throughout the rainy season caused all municipalities to experience water crises in the first year and 12 in the second. In 2020, nine of the municipalities obtained recognition. Cortez, Lima, and Sakamoto (2017) define the period from 2010 to 2016 as a multi-year drought and consider it the most severe in the last century. The authors also emphasize that the impacts could have been more severe if the reservoirs were not recharged in 2009.

During this period, the primary strategies for mitigating the effects of the drought were the distribution of water using water tankers and the opening of wells for domestic supply (Cortez; Lima; Sakamoto, 2017). The situation was more critical for agriculture as rainfed agriculture, whose production entirely depends on the regularity of rainfall, predominates in the region.

It is worth highlighting that the risk reduction measures undertaken until now have been insufficient and do not reach the entire population. As Olímpio (2013) points out, large hydraulic works projects are related to specific interests, such as supplying the capital cities, industrial centers, and agro-industries. Ensuring water supply for these activities is vital for maintaining the economy and generating jobs and income. However, they cannot override the essential human right of access to drinking water, as recommended in the National Resources Policy Water (Brazil, 1997).

However, in the municipalities of the Brazilian semi-arid region, low-income families settled on degraded land represent significant segments of the population, with low educational levels and without the necessary resources to adapt their productive activities to the climatic dynamics of the semi-arid region.

Spatio-temporal distribution of flood disasters

Regarding floods, Nunes (2015) emphasizes that in urban spaces, the impacts of these disasters are concentrated in areas with irregular occupations on the banks of water bodies. According to Silva and Ferreira (2016), changes in the forms of use and occupation of plains and banks of watercourses intensify the soil waterproofing and the straightening of river channels, which are configured as recurring public and private actions, increasing the chances of floods and increasing existing dangers. According to the authors, this problem is directly linked to the disorderly urbanization process, environmental degradation, inability to respond, and poverty.

In rural areas, the principal damages are the destruction of access roads, rupture of small dams, and crop destruction due to waterlogging, the effects of which impact the increase in the price of food and feed. In the historical series, 2004 was the first year to record severe impacts caused by floods, totaling nine crises recognized (Fig.4). This year's precipitation in the sub-basin was classified as extremely rainy (Silva, 2023).

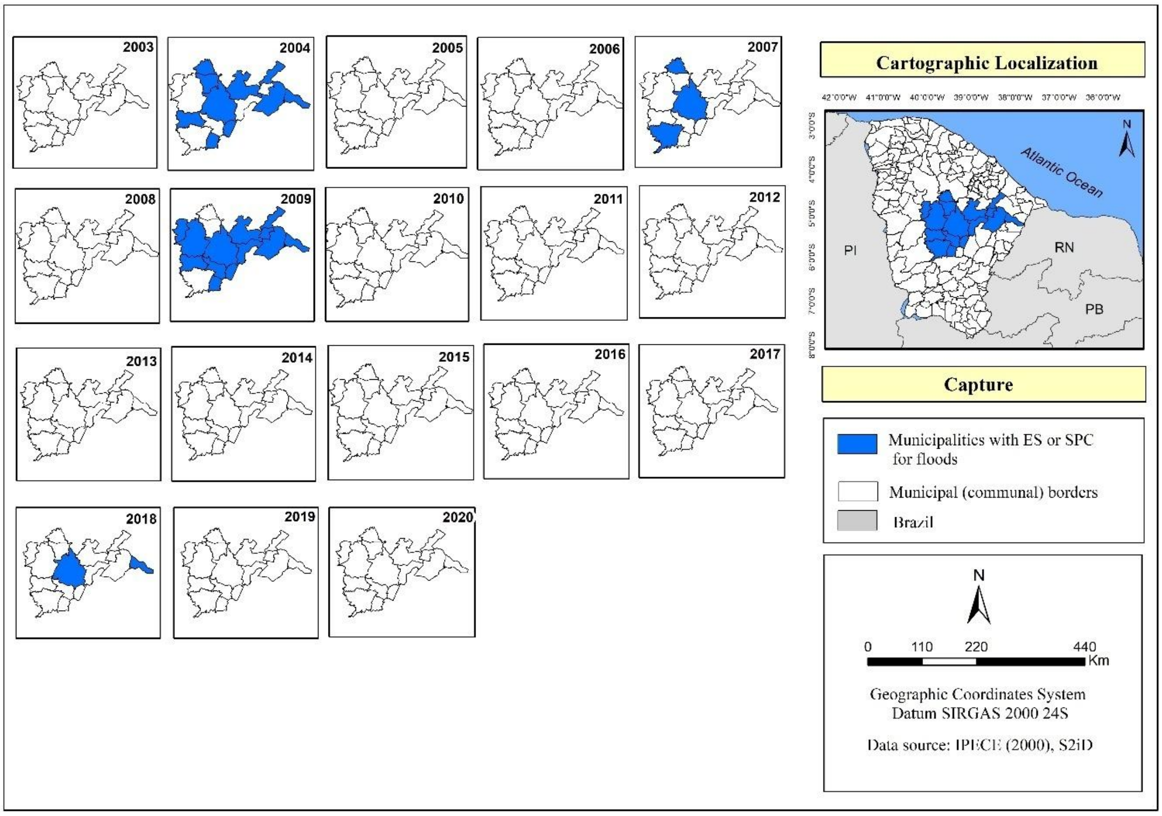

Figure 4. Spatial and temporal distribution of SEs and ECPs for floods. Source: authors.

Only in 2008 did floods cause significant impacts again. This year was considered rainy, with three decrees being recognized: municipalities of Itatira, Quixeramobim, and Mombaça.

Olímpio and Zanella (2015) analyzed the flood impacts between 2003 and 2013 in Ceará and found that 2009 was the most severe and had the most significant spatial scope. The Banabuiú River sub-basin was one of the most impacted, affecting 12 municipalities out of the 15 drained.The effects of precipitation only became severe again in 2018 when the rains caused substantial impacts in the municipalities of Limoeiro do Norte (floods) and Quixeramobim (flooding).

That said, the importance of implementing measures to reduce risks is emphasized, primarily actions to reduce vulnerabilities and not just actions to mitigate the impacts of disasters, increasing the resilience of the population that lives in the semi-arid region (Cortez; Lima; Sakamoto, 2017).

VI. Vulnerability Indicators

The consequences of extreme events are not felt equally by everyone. The poorest populations are the most vulnerable and most affected by natural disasters worldwide (Zanella, *et al*., 2009, Santos, 2021)

From this perspective, some socioeconomic indicators can reveal differences among the municipalities and identify those with the worst capacity to deal with and resist extreme events. Table 3 summarizes the socioeconomic conditions of the basin under study. Fig.5 presents the cartograms with the spatial distribution of the selected socioeconomic indicators.

Indicators	Average	Maximum	Minimum
I-1 Non-literate men	38.7	45.1	25.8
I-2 Non-literate women	11.0	15.4	7.3

I-3 Responsible men without income	19.1	27.6	10.8
I-4 Responsible women without income	3.9	5.1	2.5
I-5 Responsible men with income of up to 2 minimum wages	75.5	80.3	69.6
I-6 Responsible women earning up to 2 minimum wages	30.9	35.3	27.8
I-7 Garbage Collection	44.9	60.2	18.2
I-8 Bathroom or toilet connected to the general network	82.7	99.3	52.9
I-9 Piped water	30.5	49.6	13.0

Table 3 Summary of social vulnerability indicators.

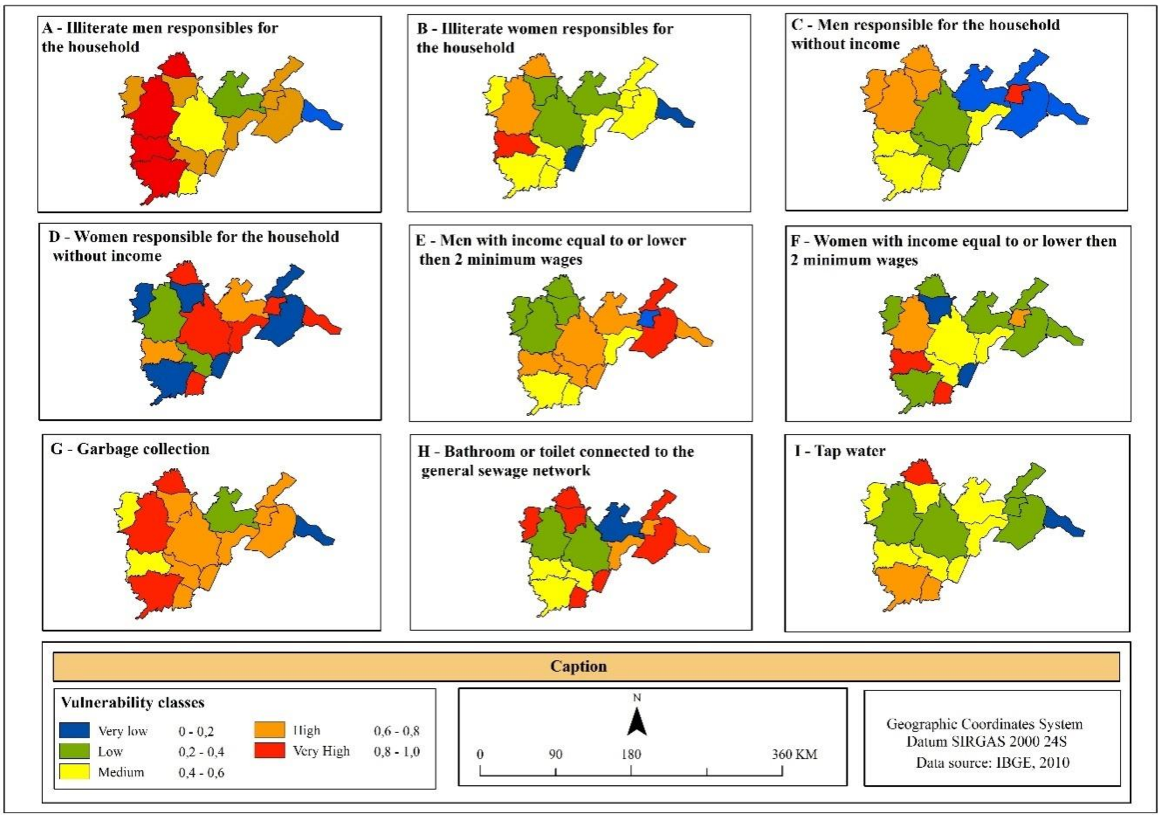

Figure 5. Spatial distribution of social vulnerability indicators. Source: authors.

Regarding educational indicators (I-1 and I-2), the municipalities presenting the worst conditions were Boa Viagem, Itatira, Pedra Branca, and Mombaça. Indeed, education is fundamental to the exercise of citizenship in society. However, it is also considered the main instrument for raising human capital levels and promoting well-being. From this perspective, Based on the idea that economic and social development cannot be treated separately from investment in people's basic needs, the World Bank adopted a political-ideological strategy electing education as one of the main tools to relieve poverty and promoting socioeconomic development Bueno and Figueiredo (2012).

Access to information and the ability to incorporate it into practical changes in everyday life are directly associated withmaterial resources and social institutions, notably the school. Therefore, the difficulties in the educational system compromise social mobility and the ability to influence political decisions and make these groups even more vulnerable (AbramovaY *et al*., 2002). According to Stoco (2011), from education, it is possible to identify how different educational facts or circumstances interfere with decisions and how they are affected by their material condition. According to the author, education is an asset that allows us to face social vulnerabilities, particularly poverty.

Regarding the number of low-income families referring to the indicators (I-3 and I-4), Ibicuitinga, Itatira, Quixeramobim, Piquet Carneiro, Banabuiú, and Limoeiro do Norte displayed the worst indicators. Due to the social structure and the lower capacity to attract public and private assets, part of the population in the municipalities has less access to better salaries and jobs, increasing vulnerability since these groups have less capacity to adapt and resist adversities caused by intense natural events, such as droughts and floods. Furthermore, they tend to live in areas more exposed to these events because housing prices are more accessible. However, they are subject to damage to physical integrity and material and property losses (Rosa; Costa, 2009).

Concerning the family arrangement referring to the indicators (I-4 and I-5), it is understood that a family formed by a spouse would be in better conditions to satisfactorily meet the emotional, financial, and work aspects of maintaining a home when only women are heads of the family, as they would have more serious difficulties in establishing the same conditions (Deschamps, 2008). Therefore, Morada Nova, Pedra Branca, and Piquet Carneiro were the municipalities with the worst conditions in these indicators.

In addition to these factors, vulnerability also occurs when the population lacks assets, resources, or structures, so their absence or insufficiency suggests that the families' standard of living is low (Costa; Marguti, 2015). Infrastructure indicators seek to reflect people's living conditions in their homes. The municipalities of Itatira, Boa Viagem and Mombaça, Monsenhor Tabosa, Madalena, Piquet Carneiro, Milhã, and Morada Nova presented the worst access conditions to this set of assets.In other words, the population in these areas is more susceptible to the risks caused by poverty and poor living conditions. This facilitates, in many cases, the transmission of infectious diseases among the family members (Confalonieri, 2003), especially during disasters when greater exposure to disease vectors occurs and food security is compromised.

VII. Analysis of the Social Vulnerability Index

For Olímpio (2017, p.178), "vulnerability assessment can be understood as an estimate of the capacity of social groups to resist and adapt to adversity, as well as to promote their well-being." Cutter (2011) states that social vulnerability explains the distribution of risks and losses, that is, the relationship between physical/social aspects and their intersections.

In this way, the Social Vulnerability Index (SVI) was created based on the integration of indicators. It is worth mentioning that SVI compares the situations present among the municipalities surveyed. Therefore, even cities with less vulnerability may contain population groups in precarious situations. Fig.6 shows the spatial distribution of social vulnerability among the municipalities investigated.

According to the methodology, the municipality of Itatira was identified as having a very high social vulnerability, presenting substantial social inequality and indicating serious poverty. In this municipality, low-income families predominate, with parents with a low educational level and a substantial lack of access to infrastructure and basic public services.

Banabuiú, Ibicuitinga, Pedra Branca, and Piquet Carneiro displayed a high level of social vulnerability, besidesprecariousness and deficits in the infrastructure, equipment and services, housing, and education sectors.

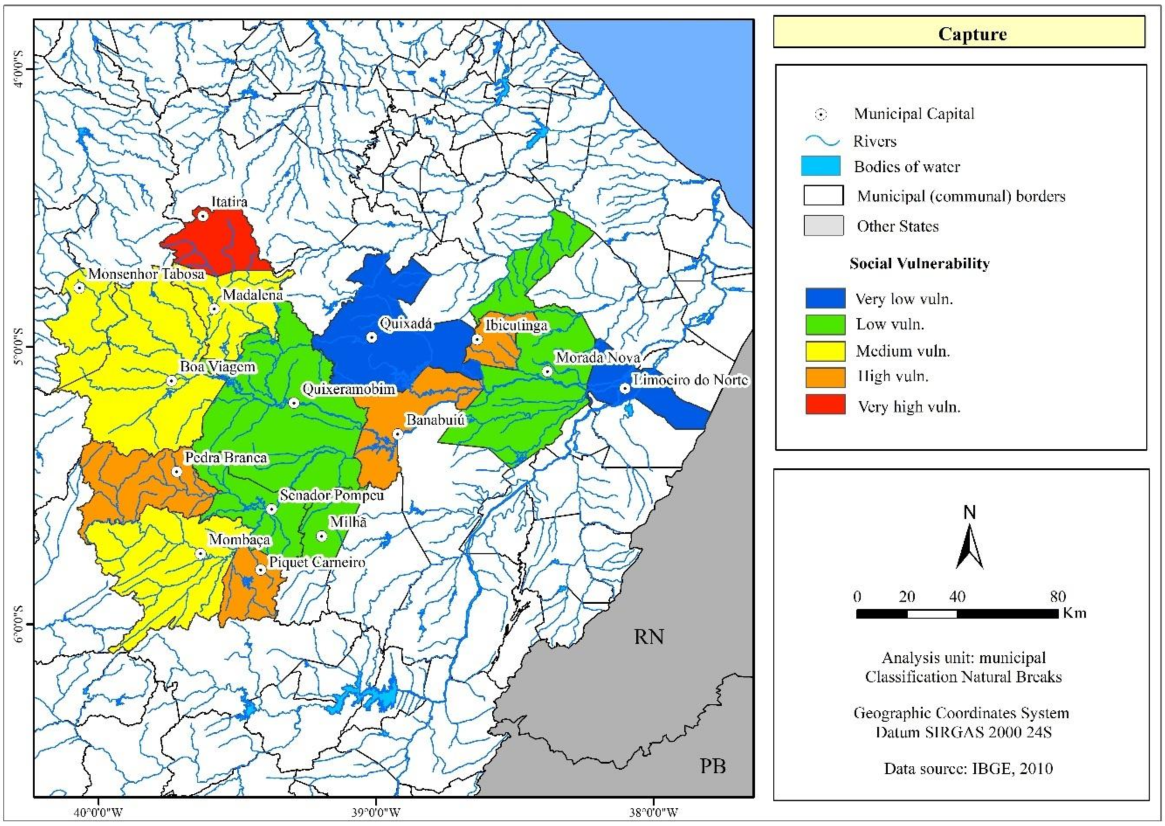

Figure 6. Social vulnerability of the Banabuiú river sub-basin/CE. Source: authors.

Boa Viagem, Madalena, Mombaça, and Monsenhor Tabosa displayed medium social vulnerability, as Morada Nova, Milhã, Quixeramobim, and Senador Pompeu presented low social vulnerability. These territories have better living conditions when compared to previous municipalities. They have a moderate to low lack of infrastructure, but these groups may enter the weakest levels of vulnerability in the event of economic crises or disorderly population growth.

Limoeiro do Norte and Quixadá presented the slightest social vulnerability. The milder conditions of these territories result from the economic size of these regional municipalities, as they act as centralizers of public and private investments, which produce a better structure of opportunities for the population.

Given the above, planning is essential for developing risk management policies and identifying potentialities and weaknesses through the social vulnerability index. From this, it is possible to formulate more solid alternatives linked to the reality of this region.

VIII. Conclusion

In this research, we sought to analyze the spatio-temporal distribution of natural disasters related to climate dynamics in the Banabuiú River sub-basin to identify the municipalities displaying the lowest and highest capacity for response and adaptation. To this end, the social vulnerability of the population was analyzed through the systematization of social indicators.

The results pointed out that even at the local level, the Banabuiú River sub-basin presents significant variability in the rainfall spatiotemporal distribution among the municipalities.

The ES and SPC recognition Ordinances analysis highlighted that the region is most affected by natural disasters caused by droughts. Of the 234 Recognition Ordinances issued, 208 were due to droughts. 26 Recognition Ordinances caused by the floods were also registered.

Concerning the social vulnerability of the Banabuiú river sub-basin, the municipality of Itatira exhibited the highest level of social vulnerability in the region, presenting the worst situations in the indicators and, therefore, with the lowest capacity to adapt and respond to an extreme phenomenon. Upper- and very upper-class municipalities represent spaces with great social inequality.

Municipalities with medium social vulnerability represent local centralities and have some capacity to deal with adversity. The low and very low classes suggest that the populations have better well-being conditions, which is related to the better structure of opportunities in the municipalities in this situation. However, it is worth highlighting that intra-municipal analyses must review socio-spatial and socio-environmental inequalities in their territories.

Disaster risk management policies must consider the social, economic, and environmental conditions of the territories. Therefore, this research contributes to the debate and planning of actions that help in the management of existing risks in the Banabuiú River sub-basin.

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