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DROUGHT RISK IN THE SEMI-ARID OF BAHIA

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Abstract

Drought is a complex and poorly understood climatic phenomenon. Drought risk studies are vital factors in formulating public policies. This research aimed to characterize the drought risk in the semi-arid region of Bahia, emphasizing the agricultural sector. To this end, risk scenarios were elaborated, considering the concepts associated with risk theory. Four key indicators were considered for vulnerability: agricultural, environmental, technological, and educational. The results indicate that the semi-arid region's risk is at least high for all drought conditions. In more intense drought conditions, the risk is critical. All the scenarios showed that due to the vulnerabilities found, drought in the region can generate a climate crisis of immeasurable proportions and consequences at different scales. We also demonstrate that the drought risk in the region seems to be more closely linked to socio-spatial particularities than to the severity of the phenomenon itself, highlighting the need for specific public policies. It was concluded, therefore, that more intense drought scenarios can increase the uncertainty of agricultural activities and intensify food insecurity, resulting in social turbulence and putting the region at high risk for agricultural activity. However, with access to appropriate technologies, sustainable agricultural and environmental management related to the region's climate rhythm, and high educational investments for the local population, it is possible to coexist with the particularities of the tropical climate in the semi-arid region.

Keywords: Precipitation, Anomaly, Disaster.

Resumo / Resumen

RISCO DE SECA NO SEMIÁRIDO DA BAHIA

A seca é um fenômeno climático complexo e pouco compreendido. Estudos de riscos à seca são fatores chave na formulação de políticas públicas. Esta pesquisa objetivou caracterizar o risco à seca no semiárido baiano, com ênfase no setor agrícola. Para tanto, elaborou-se cenários de risco, considerando os conceitos associados à teoria do risco. Para a vulnerabilidade foram considerados quatro indicadores chave: agrícola, ambiental, tecnológico e educacional. Os resultados indicam que o risco do semiárido, para qualquer condição de seca é, no mínimo, alto. Em condição de seca mais intensa, o risco é crítico. Todos os cenários obtidos evidenciaram que a seca na região, em razão das vulnerabilidades encontradas, pode gerar uma crise climática de proporções imensuráveis e com consequências em diferentes escalas. Demonstramos ainda, que o risco à seca na região parece estar mais atrelado às particularidades socioespaciais do que com a própria severidade do fenômeno, evidenciando a necessidade de políticas públicas específicas. Concluiu-se, portanto, que cenários de secas mais intensas podem aumentar a incerteza das atividades agrícolas e provocar intensidade na insegurança alimentar, além de resultar em turbulência social, tornando a região de alto risco para atividade agrícola. No entanto, com o acesso às tecnologias apropriadas, manejo agrícola sustentável e ambiental conexo ao ritmo climático da região, além de altos investimentos educacionais para a população local, é possível conviver com as particularidades do clima tropical no semiárido.

Palavras-chave: Precipitação, Anomalia, Desastre.

RIESGO DE SEQUÍA EN EL SEMIÁRIDO DE BAHÍA

La sequía es un fenómeno climático complejo y poco conocido. Los estudios de riesgo de sequía son factores clave en la formulación de políticas públicas. Esta investigación tuvo como objetivo caracterizar el riesgo de sequía en la región semiárida de Bahía, con énfasis en el sector agrícola. Para ello, se elaboraron escenarios de riesgo, considerando los conceptos asociados a la teoría del riesgo. Para la vulnerabilidad se consideraron cuatro indicadores clave: agrícola, ambiental, tecnológico y educativo. Los resultados indican que el riesgo de la región semiárida, para cualquier condición de sequía, es al menos alto. En condiciones de sequía más intensa, el riesgo es crítico. Todos los escenarios obtenidos mostraron que la sequía en la región, debido a las vulnerabilidades encontradas, puede generar una crisis climática de proporciones inconmensurables y con consecuencias a diferentes escalas. También demostramos que el riesgo de sequía en la región parece estar más ligado a las particularidades locales que a la gravedad del fenómeno, destacando la necesidad de políticas públicas específicas. Se concluyó que escenarios de sequía más intensos pueden aumentar la incertidumbre de las actividades agrícolas y provocar mayor inseguridad alimentaria, además de resultar en turbulencia social, haciendo de la región un alto riesgo para la actividad agrícola. Sin embargo, con acceso a tecnologías apropiadas, manejo agrícola y ambiental sustentable relacionado con el ritmo climático de la región, bien como altas inversiones educativas para la población local, es posible convivir con las particularidades del clima tropical en la región semiárida.

Palabras-clave: Precipitación, Anomalía, Desastre.

INTRODUCTION

Drought is a natural physical phenomenon and part of the dynamics of the terrestrial system. It is among the natural phenomena affecting the highest number of people (HAGMAN, 1984), and depending on how a geographic space deals with drought, there are significant economic losses, food shortages, epidemics, and land degradation (BEGUERÍA et al., 2010; FAVERO, SARRIERA, 2012; KESHAVARZ et al., 2013; VICENTE-SERRANO et al., 2010; WILHITE, 2011). This climatic condition also favors the increased evaporation of reservoirs and lakes, impacting irrigation, agriculture, the hydroelectric supply, and industrial development (BURITI and BARBOSA, 2018).

The Brazilian semi-arid region (BSA) naturally presents the most drought episodes (MACIEL and PONTES, 2015) and is marked by social vulnerability and the population's occupation of physically fragile areas (LOURENÇO and SOUZA, 2015). The BSA comprises an area of 969,589 km2, corresponding to 70% of the northeast region and containing about 63% of its local population (TAVARES et al., 2019). According to the last demographic census (IBGE, 2010), approximately 11.85% of the Brazilian population lives in the BSA with particular settlement characteristics, social discrepancies, and rainfall-dependent agricultural techniques, culminating in a complex equation, which results in the high vulnerability of the low-income population to climatic events (MACIEL and PONTES, 2015).

Agriculture is this region's main economic activity; most of the population resides in the countryside and carries out agricultural practices (TINÔCO, 2018). The BSA has a few localized "islands of prosperity" where agriculture is developed through modern machinery and access to irrigation. However, "rainfed" agriculture is still predominant, and crops are grown in small areas using low-technology traditional techniques (BLAMONT et al., 2002).

The periodic occurrence of droughts in densely populated regions with poor infrastructure, such as the BSA, tends to intensify other problems, such as poverty (MACIEL and PONTES, 2015). In this scenario of intense social vulnerability, environmental fragility, and local climatic particularities, the complexity and relevance of studies on drought risks in BSA are noteworthy.

Thus, the term "risk" needs to be understood as it is polysemic and has different meanings, including its definition in the different sciences (GONDIM, 2007; MARANDOLA JR. and HOGAN, 2004b; SPINK, 2001; VEYRET, 2007). In practice, it can be observed that "the various fields of knowledge are dedicated to their perspectives of the issue, defining them in their own terms, producing reflections and study methods. Some focus on practical aspects; others are more theoretical" (MARANDOLA JR. and HOGAN, 2004a, p. 95).

Based on a formula that translates a composite notion of risk (REBELO, 1999), the study of natural risks results from an integrated analysis of two sets of factors: the first relates to the environment's natural dynamics, and the second is vulnerability (V), which emerges from populations' different vulnerabilities, resulting from demographic characteristics, their economic power, their mode of political organization or their social and cultural status (CUNHA and DIMUCCIO, 2002).

In its narrowest sense, the concept of hazard reveals the spatial and temporal probability of the occurrence of an undesirable phenomenon due to its negative repercussions for society (CUNHA and DIMUCCIO, 2002). In practice, White (1974) demonstrates that for a phenomenon to be considered a hazard, it must be related to or occur in areas occupied by humans, causing damage and losses and exposing these populations to crises. It is, therefore, an event that occurs in the society-nature interface (MANDAROLA JR and HOGAN, 2004a). The probability of occurrences results naturally from the dynamic conditions of the physical-natural environment, influenced by humans' impacts on nature (CUNHA and DIMUCCIO, 2002).

On the other hand, vulnerability represents conditions determined by physical, social, economic, and environmental factors or processes (UN-ISDR, 2004). It can be understood as the characteristics of an individual or group of individuals (society) that influence the ability to anticipate, manage, and recover from an impact caused by a potentially dangerous process (WILHITE, 2011). From these perspectives, vulnerability comprises the intrinsic characteristics of a society that predispose it to suffer damage to a greater or lesser degree and can be defined as the inability of a person or group to absorb the effects of environmental changes, that is, to adapt to changes that constitute risk (COSTA, 2012).

The study of risk involves the investigation of the natural process and vulnerability. Potentially dangerous processes are analyzed according to the likelihood of their temporal and spatial probability, combined with the foreseeable consequences on society, the environment, and the territory. So, vulnerability can even be broken down into the exposure of people, the value of potentially affected goods, and social vulnerability, which essentially corresponds to individuals and society's capacity of resistance and resilience in the face of the manifestation of dangerous processes (CUNHA and LEAL, 2012).

Given the above, this work starts from the hypothesis that it is necessary to develop a drought risk assessment methodology in the semi-arid region of the State of Bahia, aiming to contribute to the discussion about the factors that lead droughts to acquire calamitous proportions and assisting in the management of this climatic risk.

The objective of this study was to spatially characterize the risk of drought in the semi-arid region of Bahia, especially for agricultural activity in the region, generating a helpful tool for managing the problems related to this phenomenon and producing a methodology applicable to other regions. Consequently, this study is a pioneer in its field, identifying the relationship between the natural process and the local population's vulnerabilities based on environmental, agricultural, technological, and educational indicators.

METHODOLOGY

STUDY AREA

The study area is the semi-arid region of Bahia, located in the Northeast of Brazil (Figure 1). This area occupies about 70% of the territory of Bahia and consists of 278 municipalities (SEI, 2020), inhabited by more than 7 million people (SUDENE, 2018).

It is an extensive area characterized by low total rainfall, irregular rainfall distribution, and high average temperatures (from 24ºC to 28ºC on average per year) (MOURA et al., 2019). The average annual rainfall varies between 600 and 800 mm, and approximately 50% is concentrated between December and March (BLAMONT et al., 2002).

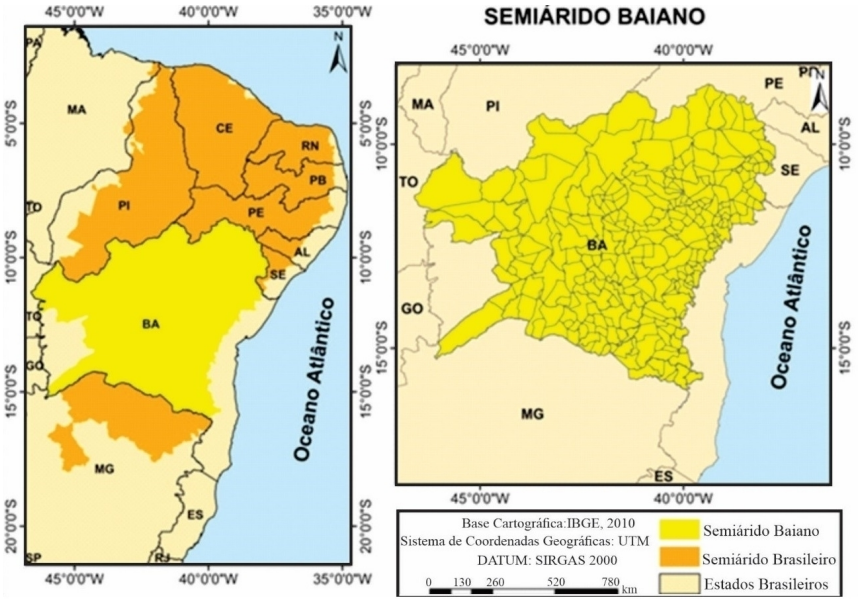

Figure 1 – Map of the location of the Brazilian semi-arid region and the Bahian semi-arid region in relation to the Northeast region of Brazil. Source: The Authors (2020).

DROUGHT RISK EQUATION

Our methodology selected Rebelo's (1999) approach, combining hazard and vulnerability factors into the concept of risk, according to Equation 1. In the present study, hazard corresponds to drought events, and vulnerability was characterized using regional indicators.

$$R = H \times V \quad (1)$$

In this sense, drought can be recorded under different conditions as a weak, moderate, severe/severe, extreme, and exceptional event (ANA, 2019; CEMADEN, 2020). The monitoring of this event is carried out through the Integrated Drought Index (IIS) and results in the six types of droughts used herein. They are: (1) normal conditions, (2) weak drought, (3) moderate drought, (4) severe drought, (5) extreme drought, and (6) exceptional drought (CEMADEN, 2021).

The vulnerability of farmers in the Semi-arid Region of Bahia was formulated according to the methodology proposed by São José et al. (2020), which suggests indicators capable of characterizing an area's conditions by its different aspects (social, environmental, technological, educational, and agricultural). The indicators presented in Table 1 are described by the variables available in the 2017 Brazilian Institute of Geography and Statistics (IBGE) and the study by São José et al. (2020).

Indicators	Variables	Source
Agricultural (IA)	Soil preparation, technical assistance, use of fertilization (chemical or organic), use of agricultural correctives, crop rotation, and irrigation.	IBGE (2017). and São José *et al*. (2020)
Environmental (IAM)	Slope protection and/or conservation; recovery of riparian forest; reforestation to protect springs, springs protected by forests.	
Technological (IT)	Internet access, electricity, and technical assistance.	
Educational (IE)	Number of people who have never attended school, attended elementary school, high school/technical school, and higher education.	

Table 1 - Variables comprising the agricultural vulnerability indexes in the region. Source: Adapted from São José (2020) and São José (2023).

Each indicator that makes up the vulnerability received a different weight (Table 2), based on Santos and Vital (2020), who established the weights according to each indicator's relevance. The weights adopted for each indicator range from 0.00 to 1.00 and can quantify the local population's vulnerability indicators.

Indicators	Weight
Environmental (IAM)	0.20
Agricultural (IAG)	0.10
Technological (IT)	0.10
Educational (IE)	0.10

Table 2- Weights used for maps in the algebraic process. Source: Adapted from São José (2022) and São José (2023).

Therefore, given Equation 1, the Drought Risk adopted in this methodology can be rewritten as follows (Equation 2):

$$\text{Drought risk} = CS + (IAG * 0.10 + AMI * 0.20 + IE * 0.10 * IT * 0.10) \quad (2)$$

Where:

CS- Drought Condition;

IAG- Agricultural Index;

IAM - Environmental Index;

IE- Educational Index;

IT- Technological Index

From Equation 2, the algebraic map process was used to map the drought risk in the semi-arid region of Bahia. Thus, for each drought condition (weak, moderate, severe, extreme, and exceptional), the different vulnerability classes were applied with their respective weights, determining the risk of drought in the semi-arid region in each scenario.

The results were divided according to the values of low risk (value from 0 to 1.0), moderate (value from 1.1 to 1.9), high (value from 2.0 to 3.0), very high (value from 3.1 to 4.0), and critical (value from 4.1 to 4.9).

RESULTS AND DISCUSSIONS

Figures 2 to 6 present the risk cartography for the five types of droughts analyzed, according to CEMADEN's classification: weak drought (Figure 2), moderate drought (Figure 3), severe drought (Figure 4), extreme drought (Figure 5), and exceptional drought (Figure 6). The figures show the critical areas for triggering climate crises associated with the full manifestation of drought risks in the semi-arid region of Bahia. It is evident that the climate risk of a weak drought (Figure 2) is high for all the municipalities in the semi-arid region of the state of Bahia. In this weak drought scenario, regional particularities do not prominently influence the categorization of the critical nature of risk since the entire region had the same high-risk classification. Therefore, it is understood that vulnerability becomes the key point for determining this risk since, in this condition, it has been verified that the public policies in the region are incapable of fostering farmers' adaptation and/or resilience during a weak drought.

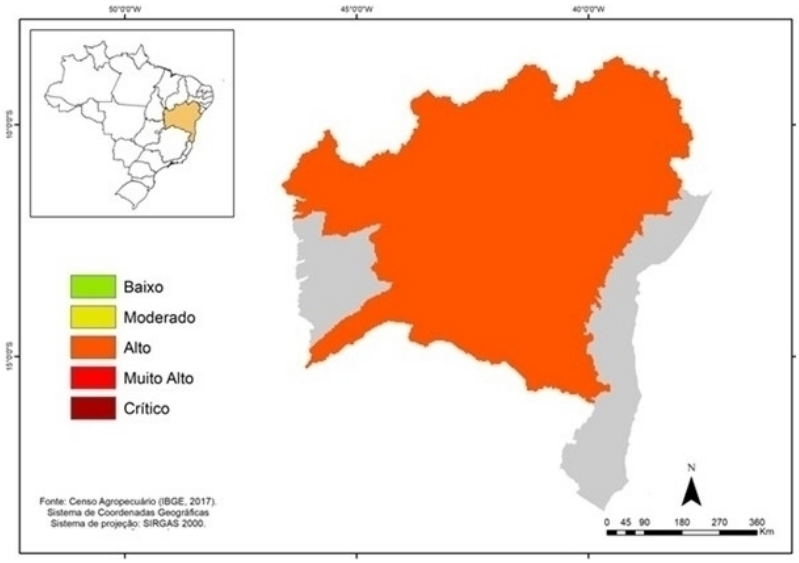

Figure 2 – Cartography of drought risk in a scenario characterized as weak drought for the semi-arid region of Bahia. Source: Adapted from São José (2023).

When analyzed from the perspective of the history of public policies in the Brazilian semi-arid region in the context of combating drought, these results suggest that a weak drought would trigger a climate crisis in the entire semi-arid region of Bahia at the catastrophic level. This trend reveals the years-long close relationship in the BSA between social vulnerability and climatic adversity. The impacts caused by droughts cannot be controlled in regions with low infrastructure, occupied by a population with low adaptability and resilience (WILHITE, 2011; Mancal et al., 2016; MARENGO, 2018; SÃO JOSÉ et al., 2020; SÃO JOSÉ et al., 2022). Therefore, the high risk in the scenario of weak drought (Figure 2) corroborates the fact that the risk of drought goes beyond the degree of severity of the climatic phenomenon.

In a situation of moderate drought projected for the semi-arid region of Bahia (Figure 3), the region shows high risk in 44 municipalities and very high in the other 234. Thus, 15.8% of the area (characterized as high risk) is liable to record a catastrophe if there is a risk of moderate drought. In most of the region (84.2%), the crisis tends to be more critical, with a high potential to assume proportions of major catastrophes if the moderate drought category is present. In this context, local vulnerabilities are a preponderant factor for the results in weak and moderate drought scenarios. According to the equation developed for map modeling, it is understood that the vulnerability indicators (IA, IAM, IE, and IT) have a significant impact when assessing the risk of drought, and, therefore, this climatic event cannot be evaluated from a single perspective.

This analysis observed the importance of adaptation and resilience policies to the BSA population, corroborating the living-with-drought approach and not only limiting the mitigation of this phenomenon's effects to episodes of greater-intensity droughts. Thus, the results show that the semi-arid region of Bahia has possible scenarios for triggering climate crises associated with droughts of weak to moderate severity.

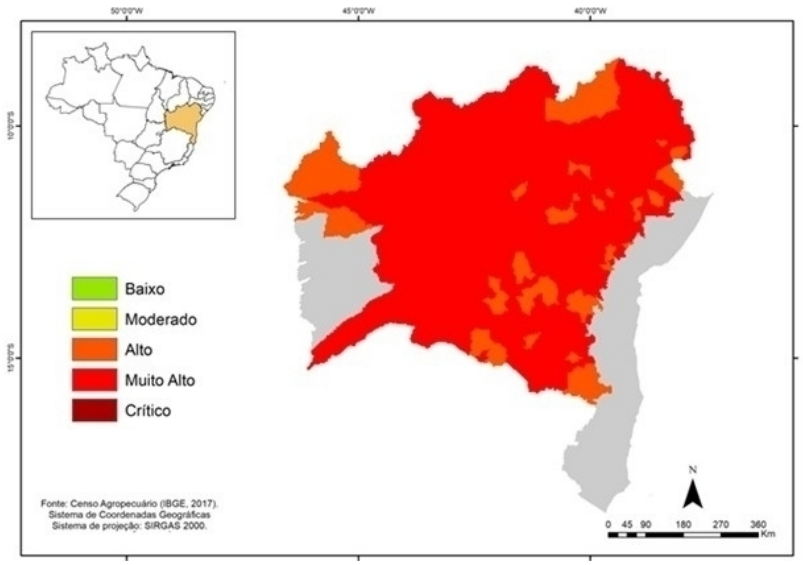

Figure 3 - Cartography of the risk in the face of a moderate drought condition for the study area. Source: Adapted from São José (2023).

However, in a scenario of severe drought, the risk evolves to higher levels (Figure 4), with the entire region presenting a very high risk and a tendency to severe crises marked by major catastrophes. From this projection, it is notable that these conditions impose significant limits on the exercise of agricultural activities in the region, which may result in losses for farmers, especially the most vulnerable. It is essential to highlight that severe drought is a potentially harmful event, and when associated with the local population's social vulnerability, it can generate incalculable social and economic impacts in the study area.

When faced with a severe drought, the region does not have favorable conditions for agricultural practices or the population's occupation and development in general due to the magnitude and severity

of the impacts and their social consequences, as was evident in the 2012 drought in the region, which resulted in public calamities. According to Marengo et al. (2016), the 2012 drought resulted in large-scale crises in the agricultural, livestock, and industrial sectors, leading to a loss of approximately 6 billion dollars since the effects of the 2012 drought lasted for years after the extreme event.

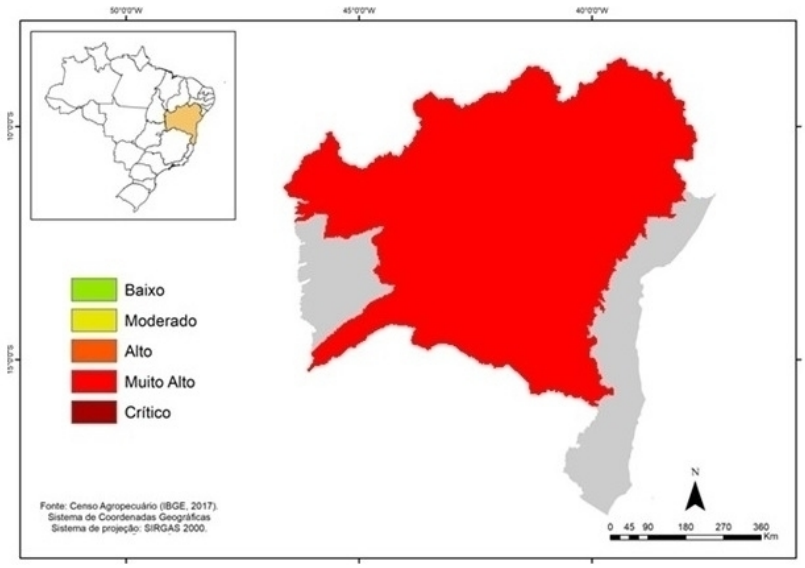

Figure 4 – Drought risk mapping considering a severe drought situation for the semi-arid region of Bahia. Source: Adapted from São José (2023).

In the case of extreme drought, the risk was classified as very high for 44 municipalities and critical for the remaining 234 (Figure 5). In this scenario, 84.2% of the region is represented by the maximum level of this climate risk, with a strong tendency to assume the proportion of a major catastrophe. In the case of agriculture, a great catastrophe translates into poor local agricultural production, given the lack of technologies consistent with the environment, which further increases food insecurity.

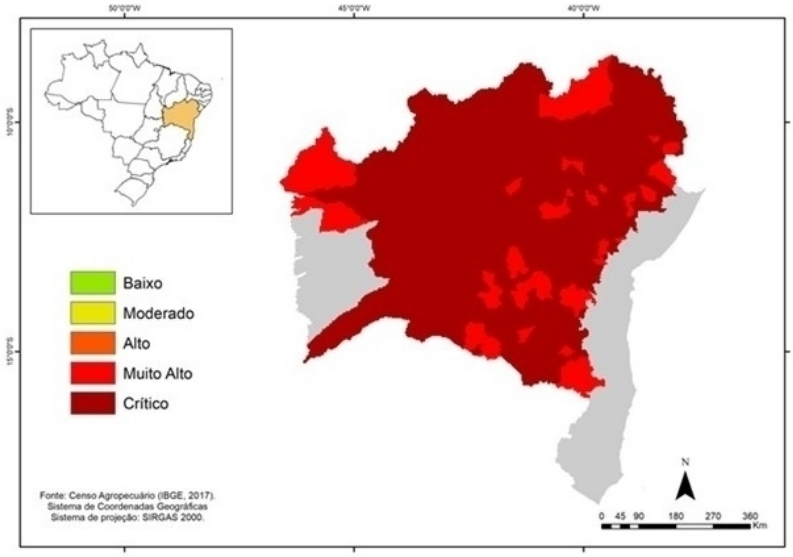

Figure 5 – Mapping the risk in the face of an extreme drought condition in the semi-arid region of Bahia. Source: Adapted from São José (2023).

This difficult-to-break cycle requires specific approaches to living with drought, involving the development of social technologies such as the cistern program and economic investments, including income transfer programs. Furthermore, breaking this cycle requires living with drought through the perspective of local appreciation, privileging cultural diversity, and reaffirming the territory's identity (SILVA, 2007).

A drought characterized as exceptional would present a critical risk to the entire semi-arid region of the State of Bahia (Figure 6), representing a catastrophic scenario if this risk materializes. Given this situation, agriculture in this region is considered a high-risk activity. This condition can be an extremely limiting factor for local agriculture since the infrastructure is not sufficiently capable of mitigating the effects caused by the drought and can, therefore, severely damage the agricultural and socioeconomic spheres.

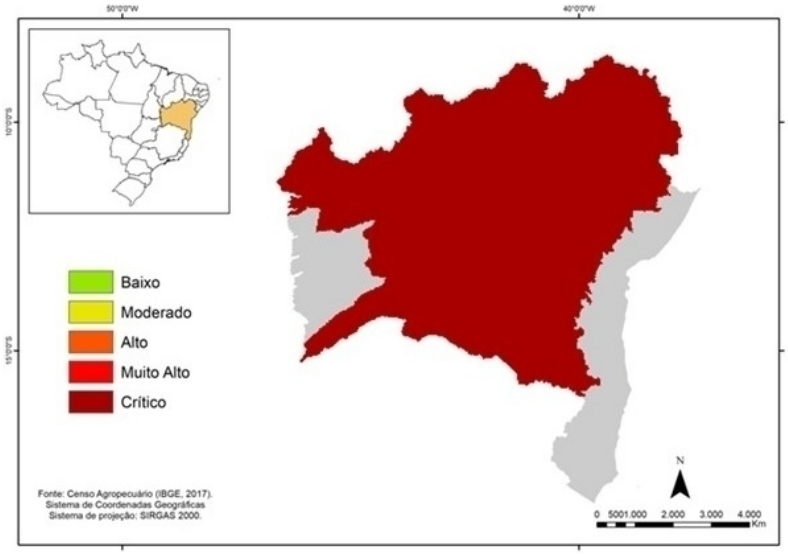

Figure 6- Risk mapping considering an exceptional drought condition for the study area. Source: Adapted from São José (2023).

Based on the projections of the calculated risks, social and economic consequences are not only associated with the severity of the climatic event (drought) since the model in question indicates high risk in the case of a weak drought, as well as high/ very high risk for the region in a moderate drought scenario. This fact promotes the argument that, in itself, drought is not the biggest or most significant limiting factor. What ultimately defines the range of risk and/or disaster in this region is the lack of infrastructure, public policies, and an adequate adaptation capacity to live with semi-aridity. Planting species unsuitable for this climate, for example, requires an amount of water the site cannot offer, leaving the population disadvantaged for these crops.

The long duration and recurrence of drought events affect the northeastern semi-arid region's economy, with social repercussions in rural areas as the region has a predominance of extensive livestock farming and rainfed family farming areas, where the occurrence of drought in intensity and extent has implications for agricultural production (MARENGO, CUNHA and ALVES, 2016). On the other hand, the model developed in the present study shows that drought's socio-environmental repercussions in the semi-arid region of Bahia are closely related to the fact that this climatic event occurs in locations with a human presence or activity in a vulnerable condition.

The severity and fatality of drought risk in this region are directly related to the occupation and appropriation of this space, which was carried out inappropriately without knowledge of local geographical characteristics. They are aggravated by environmental degradation (RAMALHO E GUERRA, 2018), unsustainable agricultural practices, and, most of all, the management model historically adopted by municipal and state governments.

The increased frequency of this climatic phenomenon will lead to a decrease in the support base for human activities, along with the forecast increase in population displacement to cities or areas where it is possible to develop irrigated agriculture (MARENGO et al., 2016). Although the model indicates that the severity and fatality of the risks are not exclusively conditioned to severe, extreme, and exceptional droughts, these episodes tend to produce more severe social turbulence.

Lastly, given global climate change, it is noteworthy that the increase in the frequency of droughts in time and space indicated by projections, coupled with unsatisfactory and low State intervention in the semi-arid region, will cause socio-environmental and economic problems that will affect not only the semi-arid region of Bahia but other states in the northeast region.

CONCLUSION

The present study characterized the risk of drought in the semi-arid region of Bahia, emphasizing the agricultural sector and identifying the relationship between potentially dangerous processes (drought conditions) and the vulnerabilities of the region's population. This methodology was able to generate a risk cartography for the different scenarios of drought conditions.

In general, the results demonstrate that in a scenario of weak drought, the population's risk of drought is considered high. In moderate drought scenarios, this risk ranges from high to very high, with most municipalities classified as very high risk. The risk will be very high in a severe drought scenario, and in extreme drought scenarios, the risk goes from very high to critical. In the scenario of exceptional drought, the risk will be critical throughout the territory.

As a result, studies on climate risk in the region are of singular relevance, primarily to provide subsidies that increase the adaptive capacity of the population exposed to natural processes and assist managers and decision-makers. However, it is necessary to use indicators that translate this reality in an integrated way and take local particularities into account.

Based on the indicators used in the present study to characterize climate risk in the semi-arid region of Bahia, it was possible to verify that this region's environmental, agricultural, technological, and educational indicators are unsatisfactory, and there is a need for public policies to improve this situation. The indicators elucidated farmers' vulnerability in the semi-arid region of Bahia and translated climate risk in a generalized way. However, further studies are needed to clarify problems associated with drought and its specificities in the semi-arid region.

The indicators also showed that agriculture is a high-risk activity in the region, affecting the socioeconomic development of the semi-arid region of Bahia and providing countless impacts on space and time, especially in the face of exceptional drought. Thus, the reality of the BSA is marked by social vulnerability and the location of the population in physically fragile areas, generating an increased climatic risk regarding drought.

The public policies related to the drought phenomenon carried out to date need to evolve. They must efficiently promote a region with adequate infrastructure capacity and a resilient population, less exposed to economic and material damage in the face of the potentially dangerous process. Therefore, public intervention adjusted to proactive management of climate risk mitigation is considered essential to construct efficient risk management of different drought conditions.

Given the above results, this study contributes to the conception of drought risk in the semi-arid region of Bahia. Furthermore, it highlights the exceptionality factor by providing a drought risk model from which information can be obtained for adequate public intervention. Therefore, this work proposes more assertive mitigation and adaptation measures, which will allow the local population's sustainable development and can be replicated in other locations.

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