

# Indicator of Agriculture Vulnerability to Climatic Extremes: A Conceptual Model with Case Study for the Northeast Brazil

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# Abstract

The Northeast Brazil (NEB) is known for its temporal and spatial variability of precipitation. Several studies have investigated this variability in order to understand the damaging episodes such as droughts and floods. The phenomenon of drought in the NEB is a complex topic due to affecting millions of people and being the object of study in several fields of knowledge. One way to try to argue about this phenomenon is through the concept of vulnerability. The "operability" of this broad concept in natural disasters is a complex task. In order to measure an indicator of vulnerability it is necessary large amount of data from different areas of knowledge, among which include: meteorology, socio-environmental, economic, public health, among other areas. The main objective of this study is to create an index of vulnerability to climate extremes (drought and flood) for the NEB and to compare this rate with those found in the scientific literature. The data that will be used in this study are from ANA (Agência Nacional das Águas), IBGE (Instituto Brasileiro de Georgrafia e Estatística), and Ministry of National integration.

# **Keywords**

SPI; Sensibility; Adaptation; Climate Changes

# **1. Introduction**

The northeast Brazil (NEB) is located in the tropics between 1° and 18° south and 35° and 48° west, and it covers an area of approximately 1.6 million km<sup>2</sup>. It is known as a region of high temporal and spatial variability of

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precipitation and, due to this variability, NEB is undergone phenomena such as drought and floods. Drought is usually characterized as a weather phenomenon that arises when there is a water deficit, due to below average rainfall expected during rainy season, compromising the environmental and socio-economic development of the region. Drought is a phenomenon that, although it happens in a slow way, it causes great impact, currently being considered as the world most relevant natural disaster [1]. In Brazil there is a distinction between the concepts of drought and dryness, being the dryness generally associated with shorter periods of water scarcity [2]. According to the author, in order to the drought considered as a disaster, it is necessary that the phenomenon acts under an ecological, economic, social and cultural system. However, internationally, no distinction between drought and dryness is made, ranking due to impacts caused by such event. Several studies have been developed in several parts of the world in order to better understand and mitigate the effects of this phenomenon [3] [4]. In order to understand the effects of climatic extremes in the different spheres of society, several studies apply the concept of vulnerability [5] [6] [7], it is not an easy concept to be applied due to several factors that occurs for its event and the nature of its impact [5] [8]. Vulnerability to weather change comprises two components: the risk of occurrence of an extreme event that can be understood as sensitivity to climate extreme (for example, drought, cyclones, El Niño, Floods) and the adaptive capacity of communities towards this event (such as material and financial resources, implementation of strategies of adaptation, etc.). Despite its frequent use in recent years, the concept of vulnerability is rarely converted into analytical measurements that can be used to prioritize intervention policies and evaluate its impact. The demand for researches and prioritizing the adaptation policy throughout society has risen from a greater conscience of extreme climatic threat [6]. [9] distinguish-despite a recent convergence due to advances in theoretical and methodological discussions, two approaches of research that are active in vulnerability science, which are: human-environmental research and the risk-hazards. The first relates to the study of environmental processes on a global scale, especially climate change and its local to global impacts ([10] [11] whereas the second carries out a research on natural hazards and disasters, their correlation with vulnerability and resilience, being incorporated in emergency management and hazards mitigation [12]-[14]). It also can be said that the first approach emphasizes environmental relations in the configuration of vulnerable spaces and the second focus more on social aspects, in forming vulnerable social groups. There is consensus between the two approaches regarding the composition of the concept which is directed by the *elements expo*sure, susceptibility and response (responsiveness or resilience capacity), and this requires measurements and representations based on the two approaches of research, environmental and social, once they complement each other. In Brazil, it is growing the number of studies dealing with the spatial hierarchy and the development of vulnerability indexes, attempting to evaluate the social and environmental inequalities and to reduce the risks linked to natural events, such as the studies of [15] [16]. Another way to analyze vulnerability is with the help of a set of indicators and to evaluate the estimation of vulnerability rates based on these indicators. These indicators are useful for studying trends and for exploring conceptual models, and have the flexibility of being applicable in different scales [17]. However, the indicators are limited due to lack of information on how these variables were chosen and rules established to determine the vulnerability index of a particular region or community [9]. These limitations have led [18] to the use of statistical tools and to correlate vulnerability of crops to drought with socioeconomic indicators in order to identify the factors that make the regions more vulnerable in China.

The main *hypothesis* of the research is that there is a relation between the spaces susceptible to hazardous natural processes, such as drought, which is a natural process linked to the dynamics of precipitation, and the areas with the worst social and economic indicators and reach to services and urban infrastructure, that is, those communities with less access to natural and technological resources. The knowledge of the vulnerability of most susceptible regions to climatic extremes will contribute to identifying the more potentially risky areas and will make possible the development and implementation of policies and measures of adaptation and mitigation of the effects caused by climate change. As the Brazilian northeast (NEB) is a region known for its climatic and environmental weaknesses and for focusing areas with great agrieconomic potential, researches that identify vulnerabilities and possible impacts in the region are demanded. The objective of this study is to develop and apply a multi scale to evaluate and quantify the vulnerability of Rio Grande do Norte (RN) to identify which areas are vulnerable to climate extremes. In order to achieve this goal, the objectives are the following:

- Developing a methodological approach that combines vulnerability aspects of drought crop with socioeconomic indicators;
- Using precipitation data and crop yield data, as well as indicators close to the adaptative capacity to evaluate

to exposure, adaptation, and sensitivity of the most vulnerable geographical micro-regions of RN.

#### 2. Study Area and Methods

# 2.1. Study Area

The RN is a Brazilian state, located northeast of the NEB. The area is 52796.791 km<sup>2</sup>, equivalent to 0.62% of the national territory and 3.40% of the NEB (IBGE, 2010). According to their geopolitical characteristics, the RN is divided into 19 micro-regions, as shown in Figure 1. The state has an average annual temperature of 25.5°C, maximum 31.1°C and minimum 21.1°C. The number of annual insolation hours is between 2400 and 2700 hours, and the coastal region standsout with even 300 sunshine days per year (IBAMA, 2007). However, according to Köppen classification, the state can be divided into three types of climate: tropical wet (As') in the east coast, with showers of autumn-winter,; tropical semi wet (Aw') in the extreme west of the state, with showers during autumn and high temperatures; and the hot semiarid (BSh), which covers almost all the rest of the state, including the north coast; its average temperature is around 26°C, while rains are irregular causing drought periods, being logged ratings below 600 mm/year [19]. According to (IDEMA, 2010), the gross domestic product (GDP) increased 5.1% in 2010. The agricultural sector had a shortage of 1.9% comparing with the 2006 figure, even with emphasis on production of sugar cane, beans, cassava, cotton. The development of irrigation techniques has resulted in large increase of productivity, strengthening exportations, especially to Europe, and mainly fruits such as melon, watermelon. According to the (IPCC, 2007) the NEB will suffer due to climate changes, events such as El Niño and La Niña will have more severe effects. The weather is the factor that provides the greatest challenges to the right management of crops. In order to have growing and development of plants, it is necessary that the climate factors, such as average air temperature (day and night), rainfall and solar radiation are in accordance to the crops requirements. The rational management of soil and water by conventional techniques are fundamental to the sustainability, in order to maintain these resources with quality and quantity enough to achieve satisfactory levels of productivity [20].





#### 2.2. Methods

This article is a preliminary study of a research team that addresses agricultural vulnerability to climate extremes in a micro region scale. The socioeconomic indicator will be the agricultural productivity to map the vulnerability, then a regional scale. The concept of vulnerability follows the one proposed by [21]:

$$V = f\left(E + S - CA\right) \tag{1}$$

where: *E* is the exposure to extreme climate (drought or flood), *S* is sensitivity of productivity to the extreme event and *CA* is the adaptive capacity of these regions to deal with the extreme event. Therefore, according to Equation (1) we can divide the analysis into three stages, the first involved the determination of sensitivity of drought productivity, developing an index of income (agriculture) farming, that will be built based on food production which food production variables are considered through temporary and permanent crops, animal and plant extraction, different from the methodology of [18] [21], which considers specific crops and estimates of productivity through a model of productive trend. In this research we used factor analysis methodology, wide-spread in studies of climate vulnerability [15] [16], in order to develop this index, IBGE data were used from 1990 to 2011. The second stage involved the use of existent rainfall data to estimate the exposure to drought by drought index (SPI), and the average number of droughts registered from 1990 to 2010. The rainfall data were acquired in EMPARN (Empresa de Pesquisa Agropecuária do Rio Grande do Norte), the period was from 1964 to 2008, and the drought occurrences were acquired from Atlas of Natural Disasters. The third stage involved the determination of an adaptation capacity index using data from the 2006 agricultural census and from the Ministry of Social Development and Fight against Hunger.

#### 2.2.1. Determining the Sensitivity Factor of Agriculture Productivity to Extreme Climates

In this study, the analysis of data will be statistically done with software R, the sensitivity is estimated by the impact to productivity associated with extreme climates (drought or flood), that will be determined by the development of an agricultural sensitivity index and for that it was used a differentiated methodology of [18]; in this study will be used multivariate statistical technique factor analysis (AF) in productive characteristics such as crops (temporary and permanent), extraction (plant and animal), defined by IBGE. The temporal range of data is from 1990 to 2011, where a subdivision into two periods was made: P1 (1990-1999) and P2 (2000-2010). This technique is widely used in studies in order to determine the vulnerability in several fields of knowledgement such as climate vulnerability [15] [16], agriculture [9] [7], the main objective of (AF), to reduce the number of variables and built a new database based on estimated factors in AF which have a degree of variability very close to original variables, that is important to know which characteristics are really needed to define the vulnerability to climate extremes and which productive areas can be more influenced by these changes. In order to apply this technique some care must be taken in accordance with the database, [22] [23] recommends that the variables are continuous or discrete, trying to avoid categorized variables; Regarding the number of observations, the more the better, according to [22], suggests the sample to have a number of observations over 50, and at least of 100 cases to ensure more robust results. Regarding the method of matching data, the analysis criteria are: the correlation matrix to present values greater than 0.30; the test of Kaiser-Meyer-Olklin (KMO) varies between 0 and 1, the closer to 1, the best adequation. [22] suggests 0.50 as acceptable level. Finally, Bartelett statistic or Bartlett's test of sphericity (BTS), where it is considered a null hypothesis ( $H_0$ ) that the matrix of correlation between the variables is a identity matrix, that is, the uncorrelated variables to test the p-value has to be significant (p < 0.05).

#### 2.2.2. Determining the Exposure to Drought

In this study, the indicator for sensitivity to drought (*ES*) will be built based on the standard drought index, the SPI proposed [24] for being of easy application and satisfactory results. The monthly rainfall data were obtained with EMPARN from 1964 to 2008. The other data to compose the *ES* will be the number of decrees of drought that the municipality has granted, in the period from 1990 to 2010. In order to calculate the *IS*, the following procedure was taken: the SPI was calculated for the shower period, then the total value was accumulated in order to generate a single value for the season, after that, the average value was calculated for the geographic micro region and finally, the reason between this value and the average value of drought enacted. This can be written as the following:

$$IS = \frac{\sum SPI}{Ns}$$
(2)

The same understanding was applied to estimate the index of abrupt flood (IB) and gradual flood (IG), as it can be seen in the equations:

$$IB = \frac{\sum SPI}{Nb}$$
(3)

$$IG = \frac{\sum SPI}{Ng} \tag{4}$$

The indicator of exposure to climate extremes will be described in the following way:

$$ES = (IB + IG) - IS \tag{5}$$

For the construction of each indicator of vulnerability  $I_{\nu}$  we applied the technique mini-max, whose formulation is the following;

$$I_{v} = \frac{I_{v_{i}} - I_{v_{\min}}}{I_{v_{\max}} - I_{v_{\min}}}$$
(6)

where:  $I_{v_{i}}$  is the indicator of vulnerability calculated for the respective micro region,  $I_{v_{max}}$  and  $I_{v_{min}}$  are the maximum and minimum values of the series, respectively.

#### 2.2.3. Determining the Adaptive Capacity to Drought

In this study two indicators will be considered: physical capital (number of establishments that use irrigation system), this factor is interesting because it is linked directly to the availability of natural resources available, in this case water. The other indicator that represents the social will be the average number of tanks built, which is a project of the federal government in fighting against drought, named SIGA-ASA, the data related of human and financial sphere, these two spheres will be explored in subsequent stages of the present research.

$$CA = \frac{\left(N_C + N_I\right)}{1000} \tag{7}$$

#### 3. Results and Discussion

AF applies to the average data set for the periods P1 and P2 selected to the AF that presents the best KMO, in other words, the AF may be performed with this database, according to [23] KMO > 0.5 the AF is acceptable. Therefore, by applying the analysis to the database subset Temporary Crop, in this set there are 10 independent variables. The same procedure will be done for subsets Permanent Crop, Vegetal and Animal Extractivism. **Table 1** shows the values of the factors, commonalities ( $h_i$ ) and unities ( $\Psi_i$ ). It is noted the presence of commonality below 0.5, according to [23] commonalities represent the proportion of the variance for each variable included in the analysis which is explained by the extracted components. Usually the minimum acceptable value is 0.50, but in this study we consider 0.6.

Observing the coefficients related to each factor for each attribute evaluated, knowing that these coefficients represent the correlation between factors and attribute, it can be noticed that the first factor is highly correlated with sugar cane, beans and tomato. [23] adopts the accepted value of at least 0.4, but for this research it is adopted value of at least 0.6. Yet, the second factor is highly correlated with watermelon and melon, and the third factor shows coefficient of 0.986 for cotton. This AF shows a total variance of approximately 67% which is acceptable since the authors as [22], who states that the total variance has to be at least 67%. It is observed that the values are nearly the same, what makes the difference is the RMS that P1 > P2, therefore adopting the KMO P2 for the subset Plant and Animal Extractivism. However, the same cannot be said to the subset Permanent Crop KMO of the second period less significant, then for the AF KMO of P1 is used, concluding that the adequacy of data may be applied to AF. The factors 1 is characterized by the dairy activity or activities that needs this component, such as cheese or other dairy products. The factor 2 is characterized by deforestation

		-F 2			
Variables –	Components factor analysis				
	Factor 1	Factor 2	Factor 3	$\widehat{h}_{i}^{2}$	$\widehat{\Psi_i}$
Cotton		0.134	0.986	0,995	0,005
Sweet Potato	0.564	-0.152	0.273	0.415	0.585
Cane Sugar	0.817	-0.236	0.192	0.76	0.240
Bean	0.875	0.124		0.778	0.212
Cassava	0.545	-0.514	0.1	0.572	0.428
Watermelon	-0.167	0.865		0.776	0.224
Melon		0.909	0.114	0.843	0.157
Corn	0.218		0.541	0.341	0.659
Tomato	-0.620	0.246	0.236	0.5	0.5
Expl. Var	0.28	0.224	0.162		
Ac. Expl. Var	0.28	0.503	0.666		

 Table 1. Factors observed for subset temporary crops—Varimax rotation.

Source: Elaborated by the author.

mainly in the semi-arid region where the semi-arid savanna vegetation is considered different from the other regions in relation to its biomass and its structure [25]. This characteristic is also reflected in factor 1, finally the factor 3 that is poultry activity. This factor model has a cumulative variance of 54%. With the release of each model, it has been created the *IdA* indicator (agricultural productivity) as **Figure 2** describes some areas where some agricultural production to be more susceptible to climatic extremes.

#### 3.1. Drought Exposure Factor

In order to determine this factor, it was necessary to determine the climatology of the studied area, mainly the rainy quarter. First we have established normal climatologically periods which are 1967-1996 and 1979-2008. The others were to verify the behavior of a temporal series in order to detect some abnormalities; however, a reduction in the intensity was observed, but the main objective was to identify the rainy period characterized from March to June—Figure 3(a).

One of the large scale weather systems that occurs in this period is the Intertropical Convergence Zone (ITCZ), which normally migrates seasonally of its position further north between August and October for positions further south, approximately 2° to 4° South between February to April, determining the quality of shower periods of the NEB [26]. However, the synoptic scale systems such as easterly waves that are responsible for the rainfall on the east coast of the NEB, are mainly in the area of forest that extends from *recôncavo* of Bahia. The coast line that surrounds the bay, until the coast of Rio Grande do Norte and finally the sea breeze system, which associated to the trade winds can penetrate 100 km to the continent causing favorable conditions for precipitation **Figure 4**. Considering that the local of study shows a high climate variability, the multivariate cluster technique is applied to group more homogeneous regions of precipitation, as it can be seen in **Figure 4**. In order to build this graph in **Figure 3(b)**, the period of 1979-2008 was used. In this temporal range we have data of demographic census (2000 and 2010), and agriculture (2006), where the data that make up the S and CA were taken. Another factor highlighted is the intensity of rainfall months in groups (C1, C3 and C4) that is March, the C5 is May and finally C1 is the end of June. In **Figure 3(c)** we have total value of precipitations where C1 has a value of 1299.4 mm and the lowest is C4 with 594.38 mm.

In Figure 4 the degree of homogeneity of rainforest for the selected periods is shown. It is observed that there is a change in the normal pattern when considering normal climatologies that are different. Figure 4(a) and Figure 4(b), the first one which is introduced in this lower similarity is the eastern part of the state or the coastal strip east from 1967 to 1996. In the second the period was 1979-2008. It is observed that the central part of the state shows less similarity. The software used to make these maps was Quantum Gis, where the interpolation of the used groups was the inverse of the distance, that is, the point that presents the greatest distance will have a lesser degree of similarity, therefore higher climatic variability makes these areas have higher impact to climatic extremes.

In Figure 5, the characterization of exposure indicator of drought (ES) is observed in the east coast area, which











B. K. N. Silva, P. S. Lucio

Mea

High







Figure 5. Factor of exposure to climatic extremes for each micro region of Rio Grande do Norte.

comprehends the micro region of Natal, and that presents the lowest values of ES in all selected periods. It is observed that for the periods there is not too much variation in the condition of high ES for the extreme. In the central area of the state the variation within these periods were not significant, however, a factor that can be well represented in dynamic of the ES for the periods of 1982-1997 and 1991-2006, Figure 5(c) and Figure 5(d), respectively. It is noticed that the condition of extreme ES has increased in micro regions of the state, as well as micro-regions that overcame from a degree considered low to a moderate or medium for this periods.

#### 3.2. Determining the Adaptative Capacity to Drought

It is understood by adaptative capacity that the way which a region deals with the effects of climate change (in this case, the drought), for the analysis of CA, a range of socioeconomic variables it is necessary [7]; considering for the AC determination, five spheres of these variables are: financial, human, natural resources, physical and social capital. However, due to lack of data representing these spheres, an adjustment only with available data may be done, similar to [21] who used, in order to determine the AC. There are two indicators: the human capital, represented by literacy rate and the financial capital (poverty rate). In this study two indicators were considered, namely physical capital (number of establishments that use irrigation system). This factor is interesting once it is linked directly to the natural resource availability, in this case water. The other indicator that represents the characteristic of government action or considers social support will be given by the average number of tanks built, a project of the federal government in fighting against drought, named SIGA-ASA. Figure 6 illustrates the CA for micro-regions of Rio Grande do Norte.

According to **Figure 6**, the micro-region of *Vale de Açu* has a maximum value of 1.3, while the micro-region of Natal a minimum of 0.1, that is, *Vale do Açu* shows a AC to climate extremes, another factor that is seen is that in the central region some micro-regions show low values, and in the coast strip low or null values, as the rate do not have history of droughts, seen in the climatology test made before; another factor that deserves to be highlighted is that the western part of Natal presents AC above 0.5; with drought history from these regions, its population must be adapted to climate extremes; the index states that it only reflects the technology used in agricultural production. According to [5] [27] that AC is linked to local socio economic characteristics, that is, not only technology should be considered, but subjects about education, health and social programs help to compose the AC. That is why Natal does not have a significant value of AC, as it has 112 establishments with the use of irrigation, but it does not have any tank, while *Vale of Açu* has 924 irrigated establishments and 380 tanks.

With the stages carried out we can now determine the agricultural vulnerability to climatic extremes that can be illustrated in **Figure 7**; it is observed a small part of the east coast changes the pattern in **Figure 7**(a) and **Figure 7**(b), which show a value considered high (above 0.6) and change later into a value considered low (0.1), and also on the dynamics of vulnerability that at average has increased between these periods. In **Figure 7**(c) and **Figure 7**(d), the micro-regions which showed extreme vulnerability remained the same, as well as the micro-regions which show values considered low. And finally **Figure 7**(d) reflects the agricultural degree of vulnerability in the period of 1991-2006 which showed a reduction of regions considered of high vulnerability to regions considered of medium vulnerability.

#### 4. Final Considerations

In this study, the concept of agricultural vulnerability to climate extremes follows the proposals of [5] [18] [21] [27] in which exposure to drought (*ES*) was determined through the SPI, it can be seen that the central state has values between high and extreme vulnerability, especially within the time interval 1979-2008. Regarding the agricultural sensitivity factor to extremes, the northwestern region of the state showed higher values, configurating that these areas are more sensitive to extremes. Considering that in these areas there are high quantity of agricultural and farming activities, as well as in the eastern part of the state, in the central part there are low values, considering the low level of productivity. The AC factor concludes the need of being improved to include socio economic and demographic subjects, but a good response was obtained with the technology used (irrigation) and social program (tanks). Finally agricultural climate vulnerability to climate extremes shows a predominance of medium to high vulnerability, except that the micro-regions where the agricultural activity is low, will show low values of vulnerability such as micro-regions of northeast coast and *Pau dos Ferros*, which show low values vulnerability.



Figure 6. Classification of adaptive capacity (CA) of each micro-region of Rio Grande do Norte.





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