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Papers

Socio-environmental Vulnerability to Drought in the Seridó Potiguar, Brazil: Building Indicators

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Keywords
Drought
Vulnerability
Semiarid
Seridó Potiguar

Abstract
Imprecise in space-time and with damaging effects, drought as a historical-natural phenomenon of high complexity has been afflicting the population of the Seridó Potiguar Region, located in the state of Rio Grande do Norte, Northeast Brazil. For centuries, the region, of state relevance, is part of the Brazilian semiarid region. This reality produces socio-spatial, socio-economic, and political-institutional conflicts. Considering this, and the fact that drought in the 21st century continues to reach disastrous proportions and cause harm to human systems, this research aimed to offer a partial overview of the socio-environmental vulnerability of the Seridó region to drought, focusing on seven key municipalities: Bodó, Caicó, Currais Novos, Ipueira, Jardim de Piranhas, Jucurutu, and Parelhas. The Drought Vulnerability Index (DVI) was applied to these municipalities, composed of the sub-indices of Exposure, Susceptibility, and Adaptive Capacity, based on socio-economic and physical-environmental variables, which were calculated, classified, and cartographically represented using the RGB color composition. After analyzing the results, it was found that the municipalities ranged from low to moderate vulnerability, which can be justified by the compensation between the variables themselves and the good indicators regarding social assistance, mixed economy, hydraulic infrastructure, and means of coping with the semiarid region.

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INTRODUCTION

In Brazil, drought and dry spells occur sporadically or seasonally in all regions of the country, but it is in the semiarid region that they happen more frequently and intensely. With an average annual precipitation of 750 mm, the semiarid region exhibits great climatic variability, irregular spatial-temporal distribution of rainfall, and high temperatures, as it is located at latitudes between 5° and 10° S, resulting in average temperatures of 25°C and maximum temperatures of 40°C.

According to Resolution of Superintendência de Desenvolvimento do Nordeste (SUDENE - Regional agency of the Brazilian government responsible for economic policies in the northeast of the country) No. 107, dated 27/07/2017, the semiarid region encompasses not only the North of Minas Gerais but also all nine states of the Northeast region, along with over 70% of their municipalities, covering an area of 969,589.4 km2 (BRASIL, 2017b). The state of Rio Grande do Norte (RN), which is one of the states in the Northeast region of Brazil, has 90.6% of its territory within the boundaries of the semiarid region (BRASIL, 2017b), representing 147 out of the 167 municipalities in Rio Grande do Norte. This reality not only gives rise to socio-spatial and socio-economic conflicts but also assumes a political-institutional character, as water prevails in the political discussions of these municipalities.

With a unique history and culture, the Seridó region is one of the most affected by droughts in Rio Grande do Norte. Created through the regionalization of Brazil into microregions by the Instituto Brasileiro de Geografia e Estatística (IBGE- Brazilian government agency responsible for demographic and economic information) in 1970, Seridó is located in the central-southern part of Rio Grande do Norte, bordering the state of Paraíba, and is composed of twenty-three municipalities in an area of approximately 9,374,063 km² within the Brazilian semiarid region (BRASIL, 2017b).

In this region, water scarcity and the socio-economic vulnerability of the population, combined with the absence of effective public policies during long periods of drought, have resulted in population migration and the economic decline of agriculture, leading to true economic disasters (crop loss), social crises (unemployment and hunger), and environmental issues (desertification and deforestation).

However, even after significant water policies implemented through the Departamento Nacional de Obras contas as Secas (DNOCS- Brazilian government agency responsible for water works in the country) and the SUDENE, actions for coexistence with the semiarid region, and a significant reduction in poverty and migration in the last 30 years, in 2017 the drought reached disastrous proportions when 153 municipalities in Rio Grande do Norte entered a state of emergency, with 5 facing water supply collapse and 28 implementing water rationing (DOMINGUES, 2019). This raises the question: "What is the reason for this phenomenon, in the 21st century, continuing to reach proportions of a natural disaster and causing widespread damage to the economy?" (BURITI; BARBOSA, 2018).

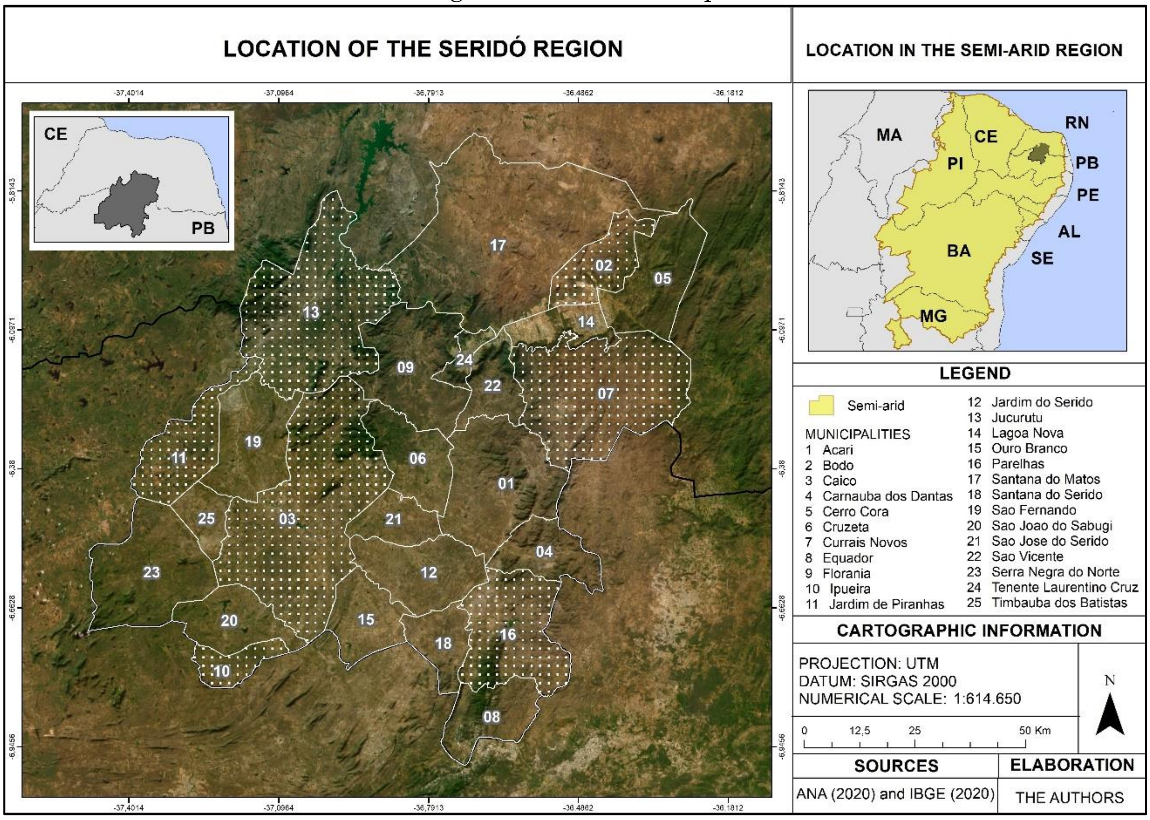
Although this fact can be partially explained by the notorious "Drought Industry" that has persisted for centuries, it is necessary to identify deficiencies in the water management system, as well as the weaknesses in the socio-economic structures of the municipalities in line with their physical and environmental characteristics and the multiple interactions of these aspects.

In light of this, and aiming to provide a partial overview of the socio-environmental vulnerability of the Seridó region, six key municipalities were selected for comparative analysis: Jardim de Piranhas, Jucurutu, Caicó, Bodó, Ipueira, Currais Novos, and Parelhas (Figure 01). These municipalities were chosen because they have a recurrence of drought disasters and variability in terms of socio-economic and physical-environmental aspects. The selection was based on three fundamental criteria for the vulnerability index identification: (I) Gross Domestic Product (GDP), (II) Human Development Index (HDI), and (III) access to water resources.

Based on the above, the surveys and analyses in this research had a temporal scope of 33 years (1984-2017), correlated with historiographical aspects, political upheavals, and socio-economic transformations over the past 500 years at the regional and national levels.

Therefore, starting from the understanding of drought and the premise that the phenomenon continues to reach proportions of a natural disaster despite strong institutional intervention, the main objective of this research is to discuss, from an interdisciplinary, holistic, and multidimensional perspective, the socio-environmental vulnerability of the Seridó region to drought through the quantification of the indices of Exposure, Susceptibility, and Adaptive Capacity to the phenomenon in the municipalities of Bodó, Caicó, Currais Novos, Ipueira, Jardim de Piranhas, Jucurutu, and Parelhas.

Figure 1 - Location map.



Source: The authors (2022).

To achieve this objective, the following specific assumptions were outlined: (I) Discuss the theme of risks and vulnerabilities related to drought in Geography in a theoretical-methodological manner; (II) Evaluate the drought vulnerability index of the selected municipalities based on the arithmetic mean of the sub-indices of Exposure, Susceptibility, and Adaptive Capacity; and (III) Contribute to the formulation of public policies related to water management, technological innovation, and mitigation of the adverse effects of drought.

THEORETICAL-METHODOLOGICAL FRAMEWORK

In the current context of modernity, vulnerability has been used according to Hogan and Marandola (2006) as the driving "idée force" of actions, analyses, and proposals by governments worldwide. This is because this specific term allows the identification of risks and hazards from the socio-spatial, economic, and political aspects of a society, since, according to the authors, "vulnerability will always be defined from a danger or a set of them, in a given geographic and social context."

Considering this,

> [...] vulnerability to environmental risks depends on social, economic, technological, cultural, and environmental factors and their relationship with the physical-natural environment, thus involving both social and environmental dynamics, the latter even when in a state of degradation" (ESTEVES, 2011, p. 75).

For this research, the understanding of socio-environmental vulnerability was adopted as a complex process related to the "coexistence, cumulativity, or spatial overlap of situations of poverty and social deprivation with circumstances of exposure to environmental risks" (BURITI; BARBOSA, p. 29).

According to Almeida (2012, p. 29), new theoretical and methodological trends related to the study of hazards started in the 1990s to approach vulnerability as a central concept for "the development of strategies for reducing and mitigating the consequences of natural disasters at various scales of analysis (local, regional, national, and global)".

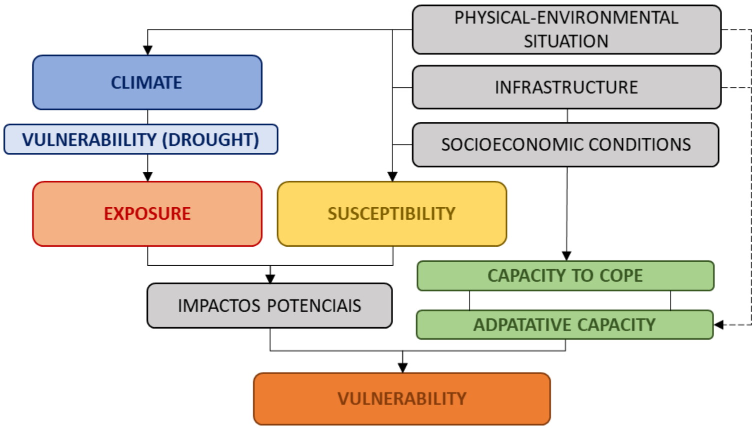
This theoretical-methodological convergence around vulnerability is driven by the current stage of modernity, where geographical and socially structural changes create a more intimate and complex relationship between risk and social security, which can be understood through the operationalization of the concept of vulnerability (HOGAN; MARANDOLA, 2006).

Due to its multidimensional approaches and addressing various aspects of reality, there are confusions and contradictions in the consensus definition of "vulnerability" in scientific literature, which implies significant difficulties in operationalizing this concept. Among these difficulties, Almeida (2012) highlights: (I) the selection and choice of studied territories and their socio-economic contexts; (II) spatial scales of analysis at the local level (city, urban rivers) or regional level (watershed, region); (III) the evaluation tools used (GIS, questionnaires); and (IV) the appropriate disciplines and professionals (geologists, engineers, and geographers).

Applicability to drought in the semi-arid region

Based on the discussions and the operationalization of different vulnerabilities, this research opted to use the Drought Vulnerability Index (DVI) developed by Rosendo (2014) for the semiarid region of northeastern Brazil, adapted by Brito (2021). This index is obtained through the equation-based integration of physical-environmental and socioeconomic variables, based on three sub-indices: I) Exposure, II) Susceptibility, and III) Adaptive Capacity, as shown in Figure 2:

Figure 2 - Representative structure of vulnerability to Climate variability.



Source: adapted by the authors based on Paiva et al. (2018).

Each sub-index has its own variables, totaling twenty-two (Chart 1 and 2), which aim to provide information and data related to climate variability and its effects in a given environmental and socioeconomic context, considering the adaptive capacity and reorganization of human systems in the face of the probability of disaster. When integrated using statistical and mathematical equations, this information will generate the Drought Vulnerability Index (DVI), which allows for a more holistic understanding of the phenomenon.

Chart 1 - Drought Vulnerability Indicators with variables.

SUB-INDEX	ASPECT	N°	VARIABLE	SOURCE	PERIOD
Exposure	Event Characteristics	1	Rainfall Anomaly Index (RAI);	EMPARN	1977-2017
		2	Aridity Index;	Jesus and Mattos (2013)	1990-2010
	Population Exposure	3	Workforce depending on agriculture (%);	IBGE	2010
		4	Rural population (%);	IBGE	2010
	Activity Exposure	5	Agricultural establishments with irrigation (%);	IBGE	2017
		6	Industrial dependency on agricultural raw materials (%);	BRASIL (CAGED)	2017
		7	Crop exposure (%);	IBGE	2017
		8	Herd Exposure (%);	IBGE/ANA	2017
Susceptibility	Socioeconomic Characteristics	9	GDP Per Capita (R$);	IBGE	2017
		10	Inequality Index (Gini);	BRASIL (DATASUS)	2010
		11	Unemployed Workforce (%);	BRASIL (CAGED)	2010-2017
	Technological Characteristics	12	Water volume of reservoirs in the reference year (%);	IGARN	2017
		13	Families not served by wells (in operation) (%);	CPRM	2020
		14	Families not served by Cisterns (%);	Morais (2016)	2015
		15	Families not served by Water Trucks (%);	Souza et al (2016)	2014
		16	Sanitation coverage (%);	BRASIL (DATASUS)	2010
		17	Rural properties using silage for forage or grain storage (%);	IBGE	2017
	Activity Characteristics	18	Degraded/unsuitable areas for agriculture (%);	IBGE	2017
Adaptive Capacity	Capacity to Cope	19	Retired population (%);	INSS	2017
		20	Municipal Human Development Index (HDI);	IBGE	2010
		21	Population served by Social Programs (%);	BRASIL	2017
	Livelihoods	22	Workforce independent of Agriculture (%);	IBGE	2017

Source: adapted by the authors based on Rosendo (2014).

Chart 2 - Description of Drought Vulnerability Indicators.

<table>
<tr><th colspan="6">EXPOSURE SUB-INDEX</th></tr>
<tr><td colspan="6">It can be defined as the nature and intensity of environmental stress, in this case, climatic, on a territory or human system, including magnitude, frequency, duration, and spatial distribution.</td></tr>
<tr><td colspan="6">ASPECTS</td></tr>
<tr><td colspan="2">Event Characteristics</td><td colspan="2">Population Exposure</td><td colspan="2">Activity Exposure</td></tr>
<tr><td colspan="2">Related to the elements that compose drought.</td><td colspan="2">Allows understanding the extent to which the population is exposed to drought</td><td colspan="2">Takes into account the types of economic activities, particularly agricultural activities.</td></tr>
<tr><th colspan="6">SUSCEPTIBILITY SUB-INDEX</th></tr>
<tr><td colspan="6">It is the degree to which a vulnerable system can be affected by disturbances, considering its socioeconomic and physical-environmental characteristics, representing the system's readiness and capacity to absorb adverse impacts without long-term damage.</td></tr>
<tr><td colspan="6">ASPECTS</td></tr>
<tr><td colspan="2">Socioeconomic Characteristics</td><td colspan="2">Technological Characteristics</td><td colspan="2">Activity Characteristics</td></tr>
<tr><td colspan="2">Refers to factors such as poverty and income inequality.</td><td colspan="2">Related to infrastructure for water treatment, distribution, and storage, as well as food-related infrastructure.</td><td colspan="2">Refers to the types of agricultural activities conducted and the conditions under which they are carried out.</td></tr>
<tr><th colspan="6">ADAPTIVE CAPACITY SUB-INDEX</th></tr>
<tr><td colspan="6">Represents the ability of human systems to minimize, cope with, prepare for, and recover from future disaster impacts. It consists of variables that reflect how the affected system will cope.</td></tr>
<tr><td colspan="6">ASPECTS</td></tr>
<tr><td colspan="3">Coping Capacity</td><td colspan="3">Livelihoods</td></tr>
<tr><td colspan="3">Takes into account the human capacity to cope with adverse events based on their socioeconomic conditions.</td><td colspan="3">Includes the socioeconomic situation of individuals, considering their available financial resources and/or income.</td></tr>
</table>

Source: The authors (2022).

Data Standardization and Index Composition

For the composition of indices, quantitative data needs to be on a scale of 0 to 1. This means that monetary, volumetric, and non-percentage variables will need to be normalized. To achieve this, the following equation was used:

$$Xnorm = \frac{(X - Xmin)}{(Xmax - Xmin)} \quad \text{(Equation 1)}$$

Where:

Xnorm = normalized value corresponding to the original;
X = value to be normalized;
Xmin = minimum value among the others;
Xmax = maximum value among the others.

Therefore, after composing the three sub-indices for each analyzed municipality, a simple arithmetic mean was calculated among them. The resulting value was on a scale of 0 to 1, representing the degree of vulnerability to drought. The means used for index composition can be observed through the following equations:

$$Simple\ Arithmetic\ Mean = \frac{A + B + C}{3} \quad \text{(Equation 2)}$$

$$Geometric\ Mean = \sqrt[n]{A + B + C} \quad \text{(Equation 3)}$$

Where:

A, B e C = Distinct Indicators;
n = Total number of indicators

Thus, the Drought Vulnerability Index (DVI) can and was expressed using the following equation:

$$IVS = \left(\frac{Exposure + Sensitivity + Coping\ capacity\ (-1)}{3}\right) \quad \text{(Equation 4)}$$

Based on other vulnerability studies that utilize multicolor compositions for graphic and cartographic representation, in this research, the final drought vulnerability index in municipalities was graphically and cartographically represented using the RGB color classification. The closer the index is to 1, the more vulnerable the municipality will be, represented by a reddish color. Conversely, the closer the index is to 0, the less vulnerable the municipality will be, represented by a bluish color, according to Chart 3.

Chart 3 - RGB Classification for the Drought Vulnerability Index

VALUE IVS		DROUGHT VULNERABILITY	COLOR	RGB COMPOSITION
Very Low	0 - 0,20	low vulnerability		R: 0 – G: 0 – B: 255
Low	0,20 - 0,40	moderate vulnerability		R: 0 – G: 255 – B: 0
Medium	0,40 - 0,60	medium vulnerability		R: 255 – G: 255 – B: 0
High	0,60 - 0,80	high vulnerability		R: 255 – G: 153 – B: 5
Very High	0,80 - 1	very high vulnerability		R: 255 – G: 0 – B: 0

Source: The authors (2022).

And to spatialize the obtained results, all sub-indices (Exposure, Susceptibility, and Adaptive Capacity) were cartographically represented using a gradient of RGY colors (red, green, and yellow), where the intensity of the color is related to the highest or lowest degree of each sub-index, according to Chart 4.

Chart 4 - RGB Classification for the Drought Vulnerability Index

VALUE OF DEGREE		EXPOSURE	SUSCEPTIBILITY	ADAPTIVE CAPACITY
Low	0 - 0,35	R: 255 – G: 79 – B: 79	R: 255 – G: 229 – B: 153	R: 168 – G: 208 – B: 141
Medium	0,35-0,65	R: 255 – G: 0 – B: 0	R: 255 – G: 255 – B: 0	R: 75 – G: 255 – B: 33
High	0,65 - 1	R: 192 – G: 0 – B: 0	R: 255 – G: 192 – B: 0	R: 56 – G: 85 – B: 36

Source: The authors (2022).

In the treatment of the obtained results, the RGB standard was used to illustrate the variables on a scale from 0 to 1. For the variables of Exposure and Susceptibility, the closer the value is to 1, the redder it is, and the closer it is to 0, the bluer it is. For Adaptive Capacity, the opposite was done since its variables are inversely proportional, as shown in Chart 5.

Chart 5- RGB Classification for Variables

VALUE	SITUATION	EXPOSURE AND SUSCEPTIBILITY	COLOR	ADAPTATIVE CAPACITY	COLOR
Very Low	Very Poor	0 - 0,20		0 - 0,20	
Low	Poor	0,20 - 0,40		0,20 - 0,40	
Medium	Fair	0,40 - 0,60		0,40 - 0,60	
High	Good	0,60 - 0,80		0,60 - 0,80	
Very High	Very Good	0,80 - 1		0,80 - 1	

Source: The authors (2022).

The cartographic production was carried out using vector and raster data from various sources, including the Agência Nacional de Águas (ANA- Brazilian government agency responsible for managing the country's waters), the IBGE, the Serviço Geológico do Brasil (CPRM- institution responsible for brazil's national geological information), the Instituto de Desenvolvimento Sustentável e Meio Ambiente do Rio Grande do Norte (IDEMA- institute of environment of the state government of Rio Grande do Norte), the Instituto Nacional de Pesquisas Espaciais (INPE- brazilian federal institute dedicated to space research and exploration), and the Instituto Nacional de Meteorologia (INMET- institute responsible for climate and meteorological information in brazil). Data processing was performed using software programs such as Excel and geoprocessing tools including Google Earth, Locus Map, ArcMap, and Quantum GIS (QGIS) 2.14 - Essen.

Fieldwork Development

Fieldwork is a methodological tool that, through verification and on-site visits to the study area, allows the research to be grounded in primary data, as well as being able to validate the theoretical-methodological framework being used.

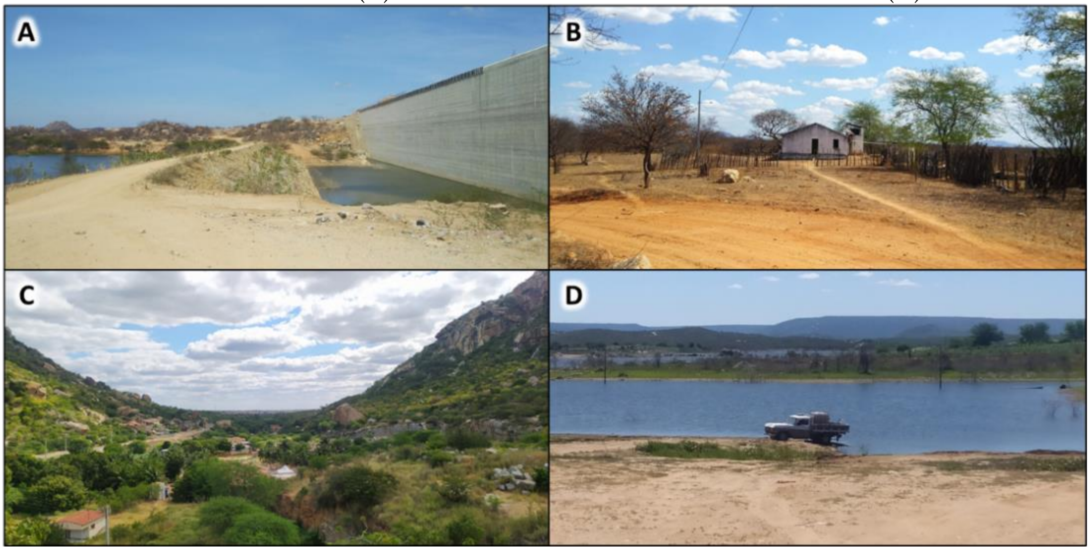
Thus, fieldwork (Chart 6 and Figures 3 and 4) was carried out between November 20th and 23rd, 2019, and on June 3rd, 2021, with the aim of recognizing the land areas of the research, identifying physical-environmental and socioeconomic aspects, and taking photographic records. In general, all municipalities (Jardim de Piranhas, Ipueira, Caicó, Jucurutu, Bodó, Parelhas and Currais Novos) were visited in both fields, and 345 images (Figure 04) of urban, rural, natural landscapes and water bodies were obtained.

Chart 6 - Fieldwork Activities Schedule

DAY	MUNICIPALITIES	ACTIVITIES PERFORMED
20/11/2020	Ipueira/Caicó	• Recognition of urban areas; • Visitation to rural areas and photographic registration of reservoirs and cisterns; • Visitation and photographic registration of Martelo and Itans dams; • Photographic registration of the landscape;
21/11/2020	Caicó/Jardim de Piranhas	• Recognition and registration of the urban center; • Visitation to rural areas and photographic registration of reservoirs and cisterns; • Photographic registration of the landscape;
22/11/2020	Jardim de Piranhas	• Recognition of the urban area of the Municipality; • Visitation and photographic registration of the Piranhas River; • Photographic registration of the landscape;
23/11/2020	Jucurutu/Caicó	• Recognition of urban areas; • Visitation to rural areas and photographic registration of reservoirs and cisterns; • Visitation and photographic registration of Oiticica Dam, Mundo Novo reservoir, and Santo Expedito and Serra de Santana pipelines; • Photographic registration of the landscape;
03/06/2021	Bodó/Currais Novos e Parelhas	• Recognition of urban areas; • Visitation to rural areas and photographic registration of reservoirs and cisterns; • Visitation and photographic registration of Dourado and Boqueirão reservoirs, Santo Expedito and Serra de Santana pipelines; • Photographic registration of the landscape;

Source: The authors (2022).

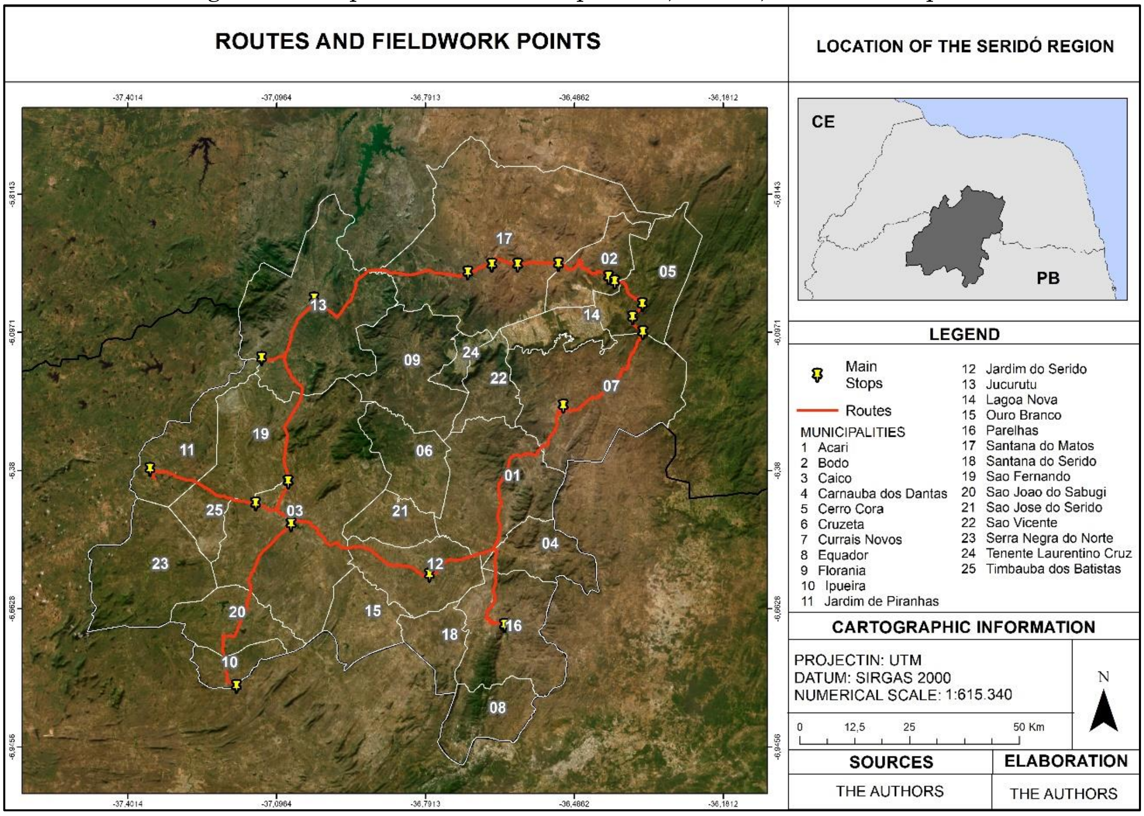
Figure 3 – Oticica Dam in Jucurutu/RN (A); Rural Area in Jardim de Piranhas/RN (B); Seridó River in Parelhas/RN (C) and Water Truck in Currais Novos/RN (D).



Source: The authors (2022).

The division of the fieldwork into two stages was conducted not only in relation to economic feasibility aspects but also to encompass, through written records and/or photographs, the semi-arid landscape during the dry and rainy seasons. Additionally, the initial visit to four of the analyzed municipalities served to validate the theoretical-methodological framework and the data used, allowing for adjustments to the research structure for the second fieldwork.

Figure 4 - Map of visited municipalities, routes, and field stops.



Source: The authors (2022).

RESULTS AND DISCUSSION

From the arithmetic mean of the 3 sub-indices (Exposure, Susceptibility, and Adaptive Capacity), the Drought Vulnerability Index (DVI) was obtained for the analyzed municipalities, namely Bodó, Caicó, Currais Novos, Ipueira, Jardim de Piranhas, Jucurutu, and Parelhas, which are in a low to medium vulnerability situation. They are represented in gradients of green and yellow colors, as expressed in Table 1 and the map in Figure 9.

Exposure, which has low to medium values, mainly driven by Rainfall Anomaly (IAC), confronts Adaptive Capacity. Although precipitation anomalies will persist, their effects can be mitigated through measures related to water infrastructure and coping strategies in the semiarid region, which, in turn, reduce Susceptibility indexes.

Table 1 - Averages of Exposure, Susceptibility, Adaptive Capacity, and Drought Vulnerability in the analyzed municipalities.

SUB-INDEX	N°	BODÓ	CAICÓ	CURRAIS NOVOS	IPUEIRA	JARDIM DE PIRANHAS	JUCURUTU	PARELHAS
EXPOSUSE	1	0,2460	0,3713	0,4502	0,3728	0,4639	0,4436	0,3158
	2	0,7557	0,7557	0,7711	0,7593	0,7548	0,7447	0,7454
	3	0,2613	0,0720	0,0650	0,1555	0,1008	0,3463	0,0756
	4	0,4256	0,0837	0,1143	0,0905	0,2155	0,4027	0,1607
	5	0,0192	0,1551	0,2832	0,0110	0,2984	0,1833	0,1980
	6	0,4000	0,6931	0,4153	0,0000	0,9348	0,8600	0,3272
	7	0,1996	0,4710	0,5004	0,6490	0,4901	0,3928	0,1802
	8	0,1299	0,3564	0,1819	0,4461	0,2732	0,3409	0,2776
EXPOSURE AVARAGES		0,30	0,3047	0,3698	0,3477	0,3105	0,4414	0,4643
SUSCEPTIBILITY	9	1,0000	0,0932	0,0838	0,0332	0,0000	0,0335	0,0713
	10	0,5259	0,5620	0,5912	0,3995	0,4607	0,4697	0,4533
	11	0,0043	0,1335	0,0877	0,0041	0,0269	0,0206	0,0521
	12	0,6600	0,9900	0,7600	0,8900	0,5000	0,5000	0,6400
	13	0,9804	0,9895	0,9908	0,9519	0,9939	0,9954	0,9871
	14	0,0000	0,8600	0,8800	0,0000	0,8500	0,8600	0,3800
	15	0,9910	0,9998	0,9978	0,9984	1,0000	0,9998	0,9990
	16	0,9842	0,2830	0,2040	0,9828	0,9494	0,7831	0,2945
	17	0,9600	0,2300	0,7800	0,7300	0,1900	0,8300	0,4400
	18	0,0322	0,0653	0,0672	0,0346	0,1216	0,1460	0,1173
SUSCEPTIBILITY AVARAGE		0,61	0,6138	0,5206	0,5443	0,5025	0,5092	0,5638
ADAPTIVE CAPACITY	19	0,1036	0,2089	0,2631	0,0969	0,1175	0,2417	0,2339
	20	0,6290	0,7100	0,6910	0,6790	0,6030	0,6010	0,6760
	21	0,8964	0,4447	0,2021	0,6539	0,2219	0,6756	0,6058
	22	0,7387	0,9280	0,9351	0,8445	0,8992	0,6537	0,9244
ADAPTIVE CAPACITY AVARAGE		0,59	0,5919	0,5729	0,5228	0,5686	0,4604	0,5430
ADAPTIVE CAPACITY AVARAGE - 1		0,41	0,4081	0,4271	0,4772	0,4314	0,5396	0,4570
DROUGHT VULNERABILITY INDEX (DVI).		**0,44**	**0,4422**	**0,4392**	**0,4564**	**0,4148**	**0,4968**	**0,4950**

Source: The authors (2022).

In regard to variable 6, Exposure, high values in the municipalities of Jardim de Piranhas, Jucurutu (Figure 5), and Caicó are noteworthy, with values above 0.50. These values directly reflect the economic activities in these municipalities, particularly in textile and dairy production. On the other hand, Ipueira (Figure 6), unlike the others, does not have any industries, which is why variable 6 has a value of zero. In addition to variable 6, Jardim de Piranhas and Jucurutu stand out with low HDI (Human Development Index) and Coverage of

Social Assistance, represented by variables 20 and 21, indicating the vulnerability of their Adaptive Capacity to drought.

Figure 5 – Production of kitchen towels in Jardim de Piranhas, RN (A) and cattle farming in Jucurutu, RN (B).

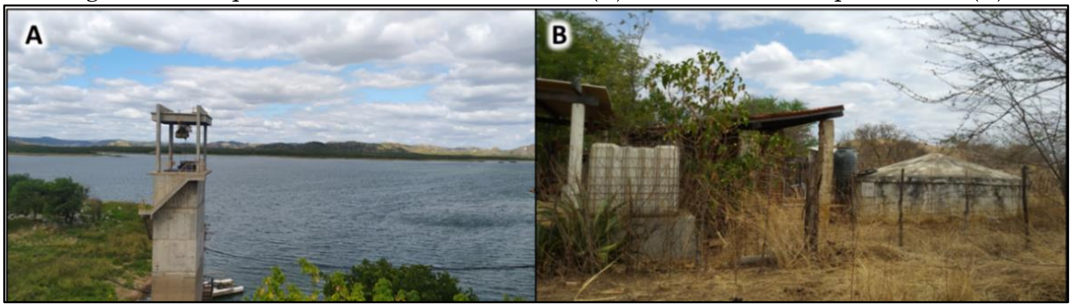
Source: The authors (2022).

In addition to the industrial and socioeconomic aspects, two other variables that deserve attention in all municipalities are the Rainfall Anomaly Index (RAI) and Aridity Index (AI). The RAI is above 0.3 in 6 out of 7 analyzed municipalities, and above 0.4 in Currais Novos, Jardim de Piranhas, and Jucurutu, reaching 0.46 in the latter, indicating high rainfall irregularity in these municipalities.

In terms of Susceptibility sub-index, Currais Novos stands out as the second most sensitive municipality to drought due to a combination of factors, including high socioeconomic inequality reflected by the Gini index, which is close to 0.6. This indicates that poorer segments of the population are more sensitive to the adverse effects of drought than wealthier ones, as well as factors related to water availability, such as reservoir levels in variable 12 and limited access to cisterns in rural areas in variable 14.

On the other hand, the municipality of Parelhas (Figure 6) is the least vulnerable to drought, justified by excellent sanitation indicators, social assistance programs, a larger population served by cisterns, and an economy based on mining and services. This municipality has better conditions to cope with drought periods and experience less intense effects.

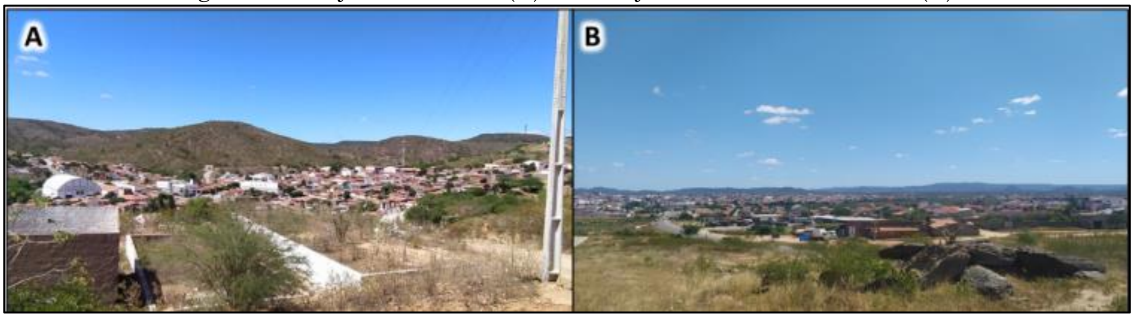
Figure 6 – Boqueirão Dam in Parelhas/RN (A) and cisterns in Ipueira/RN (B).



Source: The authors (2022).

Similarly to Parelhas, Ipueira also presents low vulnerability compared to other municipalities, however, the reasons for the index differ. In Ipueira, the population has good coverage of assistance and all rural families are benefited by cisterns, which reduces susceptibility and enhances the adaptive capacity. However, it is a municipality without economic autonomy and heavily reliant on public management.

Figure 7 - City of Bodó/RN (A) and city of Currais Novos/RN (B).



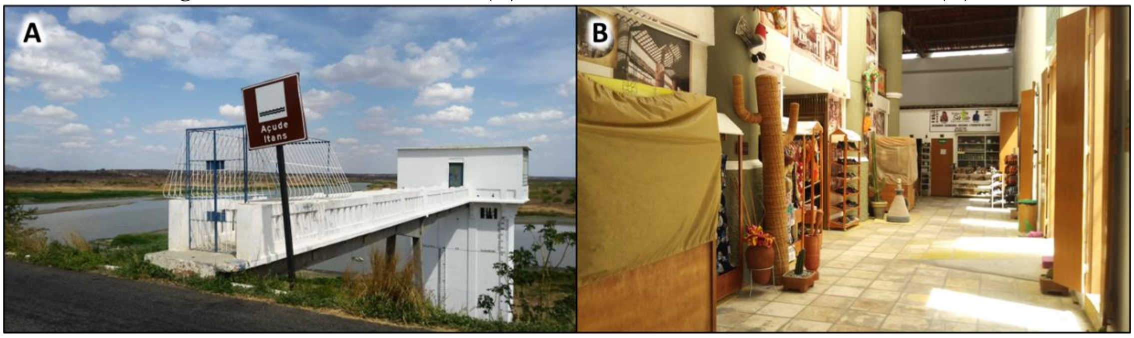
Source: The authors (2022).

The municipalities of Bodó (Figure 7) and Currais Novos have intermediate values compared to the others due to their specific characteristics. The municipality of Bodó has high susceptibility but, in contrast, has a good adaptive capacity, unlike Currais Novos, which has lower susceptibility than Bodó but a lower adaptive capacity and higher exposure due to variables such as social inequality and aridity.

The municipality of Bodó, although predominantly rural (variable 4), benefits from its location in a non-crystalline and windward mountainous region, which reduces rainfall anomalies and aridity, thus reducing its exposure to severe droughts.

Caicó, on the other hand, falls into intermediate values compared to the other municipalities. It has low susceptibility and relatively high adaptive capacity but has higher exposure compared to Bodó and Currais Novos due to considerable values of exposure in crops and livestock, as well as industrial and economic dependence on agricultural activities (Figure 8).

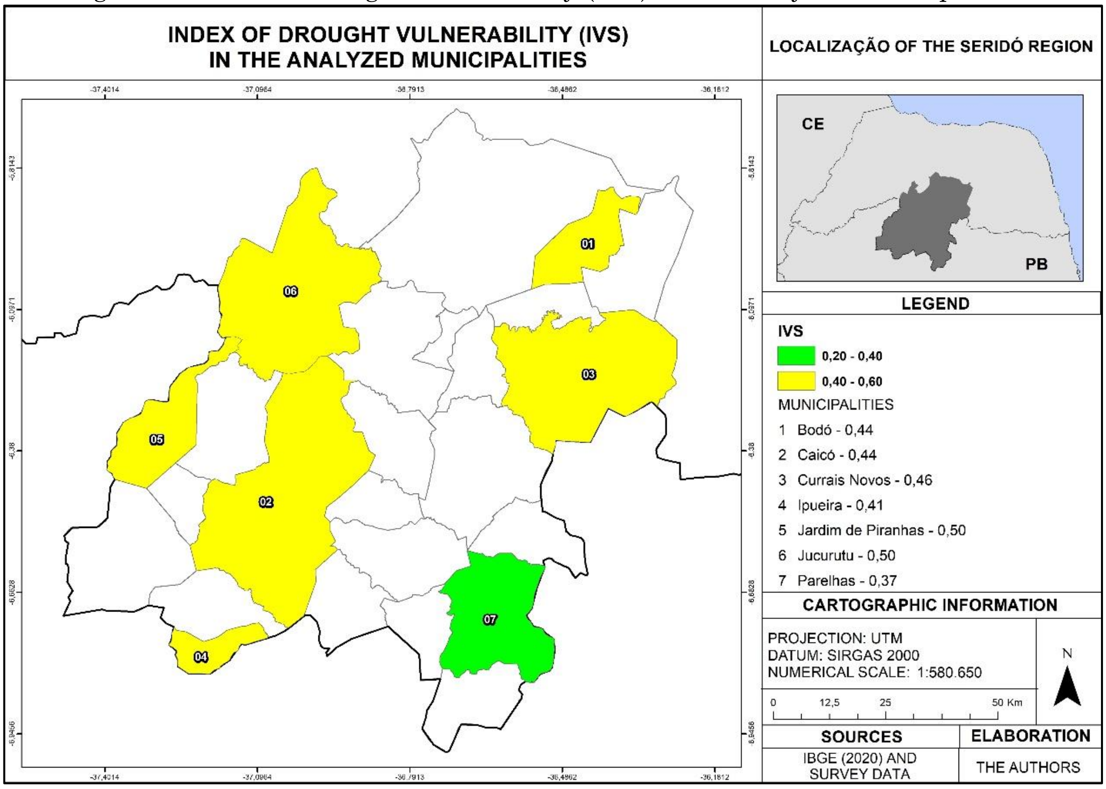
Figure 8 – Itans Reservoir (A) and Central Market in Caicó/RN (B).



Source: The authors (2022).

Strongly influenced by the relatively low indices of Exposure, moderate levels of Susceptibility, and high levels of Adaptive Capacity, the IVS in the municipalities is in the moderate range (Figure 9) due to a series of factors elucidated above, ranging from socio-economic conditions to available infrastructure.

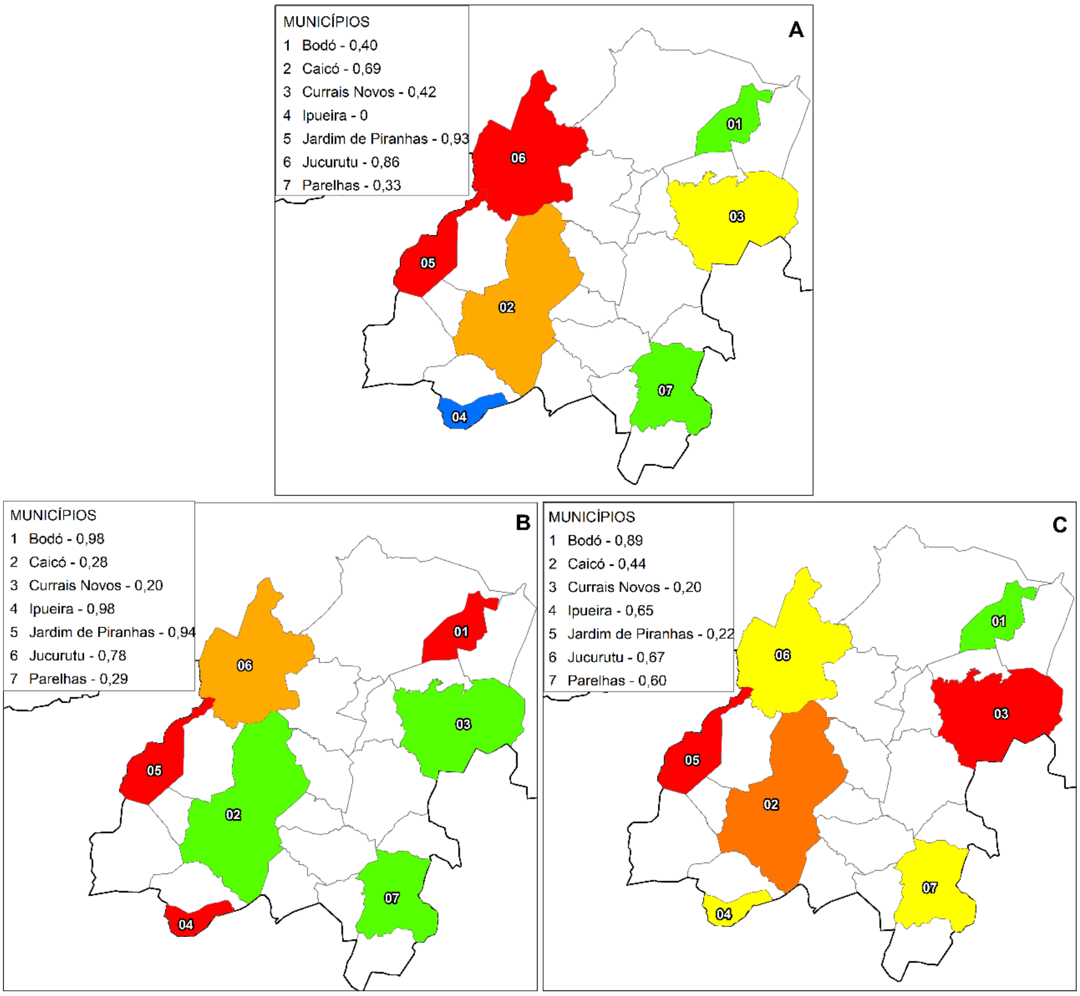
Figure 9 - Index of Drought Vulnerability (IVS) in the analyzed municipalities.



Source: The authors (2022).

Based on this, three figures (Figure 10) were elaborated according to Chart 5 of the methodology, for the variables of "Industrial Dependency on Agricultural Raw Materials," "Basic Sanitation," and "Social Assistance," as a way to cartographically illustrate the behavior and discrepancy in the values of these variables in the analyzed municipalities.

Figure 10 - Variables of Industrial Dependency on Agricultural Raw Materials (A); Lack of Basic Sanitation (B); and Social Assistance (C) in the analyzed municipalities.



Source: The authors (2022).

Based on the information in Figure 10, it is evident that the greatest deficiency in the analyzed municipalities relates to social assistance, with only the municipality of Bodó being in a "good" situation, with excellent coverage, four times higher than municipalities like Jardim de Piranhas and Currais Novos.

Regarding the variable of "basic sanitation" three municipalities are in a "good" situation (Caicó, Parelhas and Currais Novos), which are the most populous ones. However, it is still concerning that Jardim de Piranhas and Jucurutu have such low indices, being in a situation considered "poor" to "very poor" considering that the Piranhas-Assú River passes through these municipalities and may receive untreated domestic and industrial effluents.

As for the variable of "dependency on agricultural raw materials" there are high indices in the municipalities of Jardim de Piranhas, Jucurutu, and Caicó, and low indices in the municipalities of Parelhas and Currais Novos, as discussed earlier. On the other hand, the municipality of Ipueira does not have any industry, so the low value recorded does not constitute a positive aspect from an economic perspective.

Therefore, based on the information presented, we can infer that the reasons and values of the vulnerability indices for each municipality are interconnected, correlated, filled, or mutually amplified in a complex dance that is inherent to the analysis of a complex phenomenon like drought.

FINAL CONSIDERATIONS

Based on the analysis of the results and surveys conducted, we have formulated proposals for short, medium, and long term that can be adopted by each municipality analyzed here (Chart 7) regarding coexistence with the semiarid region, economic development, and environmental preservation by civil society and the government.

Chart 7 - Proposals for the analyzed municipalities.

MAIN VULNERABILITIES	MUNICIPALITIES	MAIN MEASURES	EFFECTS
Low agricultural storage capacity.	Bodó/Jucurutu	Investing in means to store and stock agricultural production, such as programs like Plano Safra and PRONAF.	LT
Low levels of basic sanitation.	Bodó/Jardim de Piranhas/Jucurutu	Investing in expanding sanitation coverage through partnerships with the state, such as CAERN (Water and Sewage Company of Rio Grande do Norte), and the federal government.	MT
Inequality.	Bodó/ Caicó/Currais Novos	Strengthening municipal tax collection and developing programs to reduce gender, racial, and income inequalities, as well as income distribution and transfers.	ST
Dependency on the agricultural sector.	Caicó/Jardim de Piranhas/Jucurutu	Diversifying the economic matrix through other sectors such as mining, geotourism, and renewable energy.	MT
Limited water resources.	Caicó/Ipueira	Promoting campaigns and developing jurisprudence against water waste, as well as expanding technologies for capturing water from alternative sources.	LT
Low coverage of cisterns, wells, and water trucks.	Caicó/Currais Novos/Jardim de Piranhas/Jucurutu/Parelhas	Investing in technologies to mitigate the adverse effects of drought through partnerships with the state government and the federal government.	MT
Insufficient social assistance coverage.	Caicó/Currais Novos/Jardim de Piranhas	Expanding assistance coverage to more vulnerable families using own resources or through federal support.	ST
High levels of rainfall anomaly.	Currais Novos/Jardim de Piranhas/Jucurutu	Implementing environmental education programs and investing in technologies for coexistence with the semiarid region.	ST
High aridity index.	Currais Novos	Promoting campaigns and developing jurisprudence against deforestation, as well as implementing reforestation and restoration programs for degraded areas.	MT
Dependency on public administration.	Ipueira	Diversifying the economic matrix through sectors such as mining, textile, bakery, and renewable energy.	MT
High exposure of crops and livestock.	Ipueira	Aligning the size of livestock herds and crops with water availability and investing in technologies that reduce extensive livestock farming practices.	MT
ST – SHORT TERM; **MT** – MEDIUM TERM; **LT** – LONG TERM.			

Source: The authors (2022).

Based on this research, it can be observed, initially, that the variables of Susceptibility and Adaptive Capacity reflect the historical negligence of the Brazilian state towards the people of the Northeastern region, considering the poor socioeconomic indicators and infrastructure. This perverse reality has been changing since the late 20th century due to the expansion, through significant social mobilization, of food security and universal access to water rights.

Furthermore, it is evident and confirmed that the Seridó region exhibits a diverse range of physical and environmental attributes, from geology to river drainage patterns and rainfall distribution, refuting any interpretation that assumes homogeneity in the geodynamics of the Northeastern region. This geodynamics, as also observed, is strongly influenced by human land use and occupation practices, which need to be controlled and sustainable. Otherwise, the resulting environmental imbalance can exacerbate the effects of drought, given that the region is naturally semi-arid.

Lastly, drought is a natural and permanent phenomenon that will recurrently affect the various inhabited areas where it is inherent. To mitigate its impact, it is necessary to invest in scientific research, political will, and strong governance and management capabilities, not only concerning water resources but also regarding political action and the complexities of the socio-environmental realm and human relationships.

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REFERENCES

ALMEIDA, L. Q. **Riscos ambientais e vulnerabilidades nas cidades brasileiras:** conceitos, metodologias e aplicações. São Paulo: Cultura Acadêmica, 2012.

ANA – AGÊNCIA NACIONAL DE ÁGUAS. **Catálogo de Metadados da ANA:** semiárido. Arquivos Shapefiles, 2020. Available: https://metadados.snirh.gov.br/geonetwork/srv/por/catalog.search#/metadata/3c8b249e-8ec3-4db1-b188-bab3c3c3240f. Accessed on: jul. 24, 2020.

BRASIL. General Registry of Employed and Unemployed Persons (CAGED). Ministry of Economy. **Municipal Profile: 2010-2017**. Data provided through the Labor Statistics Dissemination Program, 2017. Available: https://bi.mte.gov.br/bgcaged/caged_perfil_municipio/index.php. Accessed on: dec. 21, 2019.

BRASIL. Department of Informatics of the Unified Health System of Brazil (DATASUS). Ministry of Health. **Health Information (TABNET):** 2010. Avaialable: http://tabnet.datasus.gov.br/cgi/menu_tabnet_php.htm. Accessed on: jul. 21, 2021.

BRASIL. MINISTÉRIO DA CIDADANIA. **Auxílio Brasil and Unified Registry in your municipality.** 2017a. Available: https://aplicacoes.cidadania.gov.br/ri/pabcad/. Accessed on: jun. 30, 2021.

BRASIL. **Resolution No. 107, dated July 27, 2017.** Establishes Technical and Scientific Criteria for Delimitation of the Brazilian Semiarid and Procedures for Reviewing its Scope. Recife, Recife, PE, July 27, 2017b.

BRITO, A. G. M. **Vulnerabilidade socioambiental à seca: uma perspectiva do Seridó Potiguar**. 2021. 163f. Dissertation (Master's Degree in Geography) - Center for Human Sciences, Letters and Arts, Federal University of Rio Grande do Norte, Natal, 2021.

BURITI, C. O.; BARBOSA, H. A. **Um século de secas:** por que as políticas hídricas não transformaram o semiárido brasileiro? São Paulo, SP: Chiado, 2018. 434 p.

CPRM - Geological Survey of Brazil. Ministry of Mines and Energy. **Groundwater Information System (SIAGAS).** 2020. Available: http://siagasweb.cprm.gov.br/layout/. Accessed on: may 13, 2020.

DOMINGUES, F. **Desertificação atinge 13% do semiárido brasileiro e ameaça conservação da caatinga**. G1. August 20, 2019. Available:

https://g1.globo.com/natureza/desafio-natureza/noticia/2019/08/20/desertificacao-atinge-13percent-do-semiarido-brasileiro-e-ameaca-conservacao-da-caatinga.ghtml. Accessed on: jan. 27, 2020.

EMPARN – EMPRESA DE PESQUISA AGROPECUÁRIA DO RIO GRANDE DO NORTE. **Rainfall Indexes: 1977-2017**. Available: http://www.emparn.rn.gov.br/. Accessed on: sep. 03, 2019.

ESTEVES, C. J. O. Risco e Vulnerabilidade Socioambiental: Aspectos Conceituais. **Caderno Ipardes**, Curitiba, v. 1, p.62-79, 2011.

HOGAN, D. J.; MARANDOLA JR., E. As dimensões da Vulnerabilidade. **São Paulo em Perspectiva**, São Paulo, v. 20, p.33-43, 2006. 434 p.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Agricultural Census 2017.** Rio de Janeiro, 2010a. Available: https://ibge.gov.br/. Accessed on: may 02, 2020.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Demographic Census 2010.** Rio de Janeiro, 2010b. Available: http://https://ibge.gov.br/. Accessed on: feb. 16, 2020.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Territorial Boundaries 2020:** Rio Grande do Norte. Shapefiles archives, 2020. Available: https://ibge.gov.br/. Accessed on: jul. 24, 2020.

IGARN – Instituto de Gestão das Águas do Estado do Rio Grande do Norte. Ministry of Economy. **Volumetric Monitoring.** 2017. Available: https://bi.mte.gov.br/bgcaged/caged_perfil_municipio/index.php. Accessed on: feb. 04, 2020.

INSS – INSTITUTO NACIONAL DO SEGURO SOCIAL. **Quantity of benefits issued by the National Institute of Social Security - INSS, in Brazilian municipalities, according to species groups.** Brasília, 2017. Available: https://www.gov.br/trabalho-e-previdencia/pt-br. Accessed on: feb. 16, 2020.

JESUS, E. dos S.; MATTOS, A. **Análise espaço temporal da evapotranspiração sobre a microrregião do Seridó no Estado do Rio Grande do Norte**. HOLOS, [S. l.], v. 6, p. 22–32, 2013. https://doi.org/10.15628/holos.2013.1713.

MORAIS, H. A. R. **Evaluation of the One Million Rural Cisterns Program (P1MC):** effectiveness, efficiency, and effectiveness in the territories of Rio Grande do Norte (2003/2015). 2016. 85 p. Dissertation (Master's) - Administration Course, Center for Applied Social Sciences, Federal University of Rio Grande do Norte, Natal, 2016. https://doi.org/10.18764/2178-2865.v21n1p133-158

PAIVA, A. L.; OLIVEIRA, H. E. L.; GOMES, J. F. Memória social, políticas públicas e estratégias locais de enfrentamento da seca no Rio Grande do Norte. In: NATIONAL CONGRESS OF SEMI-ARID DIVERSITY, 2018, Natal. Proceedings [...]. Natal: Conadis Journal, 2018. p. 0-10.

ROSENDO, E. E. Q. **Development of indicators of drought vulnerability in the Brazilian semiarid region.** 2014. 137 p. Dissertation (Master's) - Geography Course, Technology Center, Federal University of Paraíba, João Pessoa, 2014.

SOUZA, J. L. SANTOS, M. P. S.; GUEDES, M. L. M.; ALMEIDA, L. Q. Água sobre rodas: The use of water trucks as a response measure to drought in Seridó Potiguar. In: 1st INTERNATIONAL CONGRESS OF SEMIARID DIVERSITY, 2016, Campina Grande. Proceedings [...]. Campina Grande: Realize, 2016. Vol. 1, pp. 1-13.

AUTHORS CONTRIBUTION

Anderson Geová Maia de Brito, author of the research and responsible for its construction, uses the most diverse scientific sources for the theoretical-methodological structuring of the study. Requested and obtained financial support from the Universidade Federal do Rio Grande do Norte, resources with which he carried out all the field activities, obtaining in them, images, cartographic material and data that underpinned the entire research. Lutiane Queiroz de Almeida played the role of guiding professor, instructing and perfecting the research, mainly with regard to the methodological scope used, providing bibliographies and data that supported the analyzes carried out. She corroborated the constant requests for financial assistance for field activities as well as for any other activities.