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## Climate change and biodiversity: An analysis of the ecosystem integrity of Eastern Cariri, Paraíba

### *Climate change and biodiversity: An analysis of the ecosystem integrity of Eastern Cariri, Paraíba*

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**Abstract:** The study, conducted in Paraíba, analyzed the climatic conditions and the ecological integrity of the municipalities of Alcantil, Barra de Santana, and Riacho de Santo Antônio, located in the Eastern Cariri, over a 10-year time series. The research cross-referenced annual average temperature and rainfall patterns, highlighting climate variability and its impacts on the biodiversity of Eastern Cariri. In Alcantil, there was a strong fluctuation in rainfall, with extremes of 200 mm in 2016 and 550 mm in 2022, associated with an increase in average temperature in 2023 (25.9 °C), resulting in water stress and vegetation fragmentation. In Barra de Santana, rainfall ranged from 250 mm (2015–2017) to 700 mm (2022), while average temperatures also rose, intensifying the loss of plant and animal species.

In Riacho de Santo Antônio, the hydrological regime showed strong irregularity, with minimums of 150 mm in 2015–2016 and maximums in 2022, contrasting with the rise in temperatures in 2023, which further increased the degradation of the native vegetation.

To assess the relationship between climate and biodiversity, an Eastern Cariri Ecological Integrity Index (ICECO) was proposed and developed, calculated from metrics of vegetation cover (VC), climate vulnerability (CVu), and ecological resilience (ER), supported by the R package and spatial analysis in QGIS. The results showed very distinct values among the municipalities: Alcantil (ICECO = 0.48), Barra de Santana (ICECO = 0.75), and Riacho de Santo Antônio (ICECO = 0.65). These indices revealed greater vulnerability in the municipality of Alcantil, due to reduced vegetation fragments and edge effects, while Barra de Santana shows greater adaptive capacity, and Riacho de Santo Antônio is in an intermediate condition, with potential for ecological recovery.

It is concluded that the semi-arid region of Eastern Cariri faces severe climatic instabilities; however, it presents resilient ecosystem conditions despite high temperatures, prolonged droughts, and anthropogenic activities. The use of ICECO proved effective in measuring the impacts on biodiversity and may even support conservation policies, environmental management, and socio-environmental justice in the studied region.

**Keywords:** Semi-arid; Eastern Cariri; Biodiversity; Ecological integrity; Climate change

**Resumo:** O estudo, realizado na Paraíba, analisou as condições climáticas e a integridade ecológica dos municípios de Alcantil, Barra de Santana e Riacho de Santo Antônio, localizados no Cariri Oriental, numa sequência temporal de 10 anos. A pesquisa realizou o cruzamento entre a temperatura média anual e o regime pluviométrico, destacando a variabilidade climática e seus impactos sobre a biodiversidade do Cariri Oriental. Em Alcantil, verificou-se uma forte oscilação pluviométrica, com extremos de 200 mm em 2016 e 550 mm em 2022, associada a aumento da temperatura média em 2023 (25,9 °C), resultando num estresse hídrico e na fragmentação da vegetação. Em Barra de Santana, as chuvas oscilaram entre 250 mm (2015-2017) e 700 mm (2022), enquanto as temperaturas médias também se elevaram, intensificando nas perdas de espécies vegetais e animais. Já em Riacho de Santo Antônio, o regime hídrico revelou forte irregularidade, com mínimos de 150 mm em 2015-2016 e máximos em 2022, em contraste com o avanço das temperaturas em 2023, o que ampliou a degradação da vegetação nativa local. Para avaliar a relação entre o clima e a biodiversidade, foi proposto e desenvolvido um Índice de Integridade Ecológica do Cariri Oriental (ICECO), calculado a partir de métricas de cobertura vegetal (CV), vulnerabilidade climática (VC) e resiliência ecológica (RE), sob suporte do pacote R e análise espacial no QGIS. Os resultados apontaram valores bem distintos entre os municípios: Alcantil (ICECO = 0,48), Barra de Santana (ICECO = 0,75) e Riacho de Santo Antônio (ICECO = 0,65). Esses índices revelaram maior vulnerabilidade no município de Alcantil, devido aos fragmentos vegetais reduzidos e o efeito de borda, enquanto Barra de Santana apresenta maior capacidade adaptativa, já Riacho de Santo Antônio do Cariri se encontra numa condição intermediária, com potencial de recuperação ecológica. Conclui-se que a região semiárida do Cariri Oriental enfrenta instabilidades climáticas severas, no entanto, apresenta condições ecossistemas resilientes, apesar das temperaturas elevadas, as secas prolongadas e as atividades antrópicas. O uso do ICECO demonstrou-se eficaz em mensurar os impactos sobre a biodiversidade, podendo até subsidiar políticas de conservação, manejo ambiental e justiça socioambiental na região estudada.

**Palavras-chave:** Semiárido; Cariri Oriental; Biodiversidade; Integridade ecológica; Mudanças climáticas

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## 1. Introduction

The Eastern Cariri region in Paraíba, located in the northeastern semi-arid region, is one of the areas most sensitive to climate change in Brazil. It cannot be described simply as an area prone to desertification or severe degradation, but rather to detail and specify that it is dominated by a hot semi-arid climate (BSh according to the Köppen classification) with high interannual variability in precipitation, with average annual precipitation varying between 400 mm and 700 mm, concentrated in a short rainy season followed by long periods of drought (INMET, 2024). Irregular and scarce rainfall, combined with rising average temperatures, aggravate the process of environmental degradation, putting local biodiversity at risk, which is already under constant human pressure.

According to the Intergovernmental Panel on Climate Change (IPCC, 2023), ecosystems in semi-arid regions are among the most vulnerable to climate change, mainly due to their limited capacity to adapt and increasing activity on natural resources. The increased frequency and intensity of extreme events, such as prolonged droughts, has led to the loss of native vegetation cover, aggravating desertification processes, a phenomenon already observed in several areas of Cariri, Paraíba (MMA, 2022). Paraíba stands out for having one of the highest rainfall variations in its regions, especially in municipalities such as Alcantil, Santo Antonio, and Barra de Santana, located in the micro-region of Cariri Oriental in Paraíba, where annual averages accumulate below 500 mm, quite different from the areas of the eastern axis of the state, where the accumulated amount corresponds to 1,500 mm annually (AESA, 2024).

The native ecosystem of the Caatinga Biome is generally composed of thorny and dry vegetation, typical of xerophytic species, and this type of semi-arid biomass is strongly decomposed physiologically when combined with high temperatures due to the climatic conditions of the region (Salgado et al. 2015). Given this context, local biodiversity consists of plant species adapted to the dense caatinga and highly endemic animals. Plant species such as *Pilosocereus gounellei* (xique-xique), *Cereus jamacaru* (mandacaru), and *Mimosa tenuiflora* (jurema-preta) are not only important ecological elements but also important sociocultural and economic resources for local communities (Cavalcante et al. 2013). Among this fauna, some rodents such as the mocó and the preá, some reptiles such as the teiú lizard and the chameleon, and mammals such as the peba armadillo, the maned wolf, and others such as the fox and the anteater stand out (Romero, 2011).

The Food and Agriculture Organization of the United Nations (FAO, 2021) warns that biodiversity loss in arid and semi-arid regions is damaging the resilience of local food systems and will reduce the capacity of ecosystems to provide essential environmental services, such as water regulation, nutrient cycling, and natural pest control. In the Eastern Cariri region of Paraíba, these services are essential for the survival of rural populations that depend on family farming and the collection of biodiversity products. Therefore, given this textual framework, understanding the climate regime of Cariri Paraibano and its impact on biodiversity also requires a critical analysis of environmental public policies and local climate governance. Therefore, this study aims to analyze and generate technical responses based on the construction of indicators related to ecological, social, and institutional aspects, providing a comprehensive diagnosis of the vulnerability of biodiversity and the potential of the region's municipalities in the face of climate change.

## 2. Methodology

The municipalities in the study area (Figure 1) comprise the Eastern Cariri region, with analysis of the municipalities of Santo Antonio (between coordinates 7°21'20"S 36°03'40"W), Barra de Santana (7°31'01" S, 36°00'08") and Alcantil (7°44'32"S, 36°03'49") are located in the Eastern Cariri region of the state of Paraíba, in the semi-arid northeast of Brazil. The region has a hot and dry climate, with low rainfall and high interannual variability, which imposes many restrictions on land use and environmental protection. According to the National Institute of Meteorology (INMET, 2021) and the Brazilian Institute of Geography and Statistics (IBGE, 2021), the predominant climate is hot semi-arid (BSh, according to Köppen-Geiger), with an average annual temperature of around 26°C and average precipitation of less than 600 mm/year between February and May.

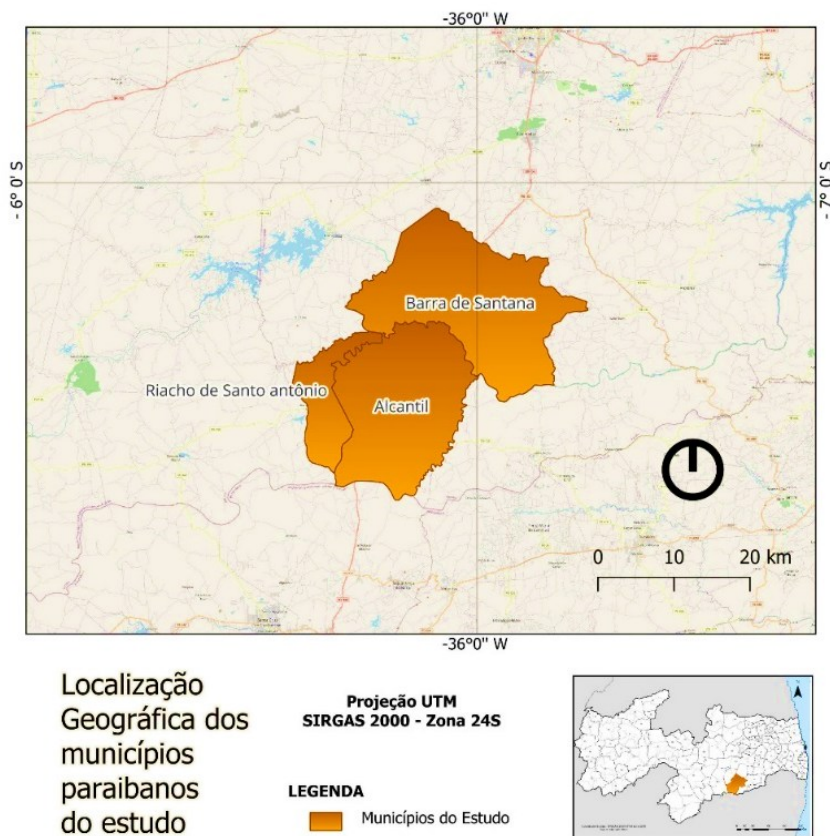


Figure 1 – Location of municipalities as study areas in the state of Paraíba.  
Source: Author (2025).

The main vegetation consists of Caatinga shrubs and trees, adapted to low humidity and shallow soils, including drought-tolerant species such as juazeiro, jurema-preta, xiquexique, and mandacaru (Silva, 2015). Part of this vegetation has been replaced by pastures and subsistence agriculture (especially corn and beans, typical of the region), which, if not managed sustainably, only aggravate soil degradation processes. Hydrologically, the region is intermittently crossed by watercourses, especially the Paraíba River, which is crucial for local water security, although its flow has decreased during prolonged droughts (ANA, 2020). Small dams, ponds, and cisterns are the main forms of water collection and storage by rural communities.

The method used has an interdisciplinary and qualitative approach, combining an ecological and sociological focus. The methodological construction is inspired by and adapted from the studies by Acuña-Alonso et al. (2021), who used hydrological models and indicators to assess the ecological integrity of river basins, and Almeida (2019), who proposed a sociological interpretation of climate risks based on environmental inequalities and social vulnerability.

The ecological assessment was associated with some phytogeographic factors of the municipalities studied, proposing the Cariri Ecological Integrity Index (ICEC), adapted from Acuña-Alonso et al. (2021), as a macro-indicator focusing on three aspects:

- Vegetation composition;
- Climate vulnerability;
- Ecological resilience.

Each of these is composed of micro-indicators, which are composed of:

#### Vegetation Composition

- Data sources: Landsat 8 (OLI) and Sentinel-2 (MSI) satellite images acquired between 2013 and 2023, with the atmosphere recalibrated using the DOS1 algorithm and a cloud mask, through QGIS 3.34;
- Use of IVDN to diagnose the vitality of native vegetation cover, on a scale of -1 to 1.
- Use of the LecoS plugin to assess ecology by spatially exposing a regeneration profile or not (using the spot metric), with results in Excel.

Due to qualitative analysis, in terms of anthropic actions and climate vulnerabilities, it is possible to obtain significant geospatial responses (FEITOSA et al., 2010).

#### **Climate vulnerability**

- Data source: time series of temperature (°C), precipitation (mm), and number using data from INMET, AESA, and FUNCEME for the period studied between 2012 and 2023. The composition was acquired for the purpose of analyzing and observing the sequences of days with precipitation below 1 mm and the slopes of the annual average temperature to compose the application with a weight between 0 and 1, that is, generating a scale of high temperature and very dry days (1). All based on the proposal by the authors Acuña-Alonso et al. (2021).

#### **Ecological Resilience Indicators**

- Data source: botanical inventories of local fauna, use of data from the UFPB Herbarium, and regional and municipal scientific publications. The purpose is to evaluate:

1. Forest areas in good condition, with a binary variable (0 = absent; 1 = present); and pastures, per km<sup>2</sup>, which is a negative condition (0).

The multi-criteria assignment proposed by Acuña-Alonso et al. (2021) was adjusted for the integrity of the Caatinga landscape, with adaptation also for observations of ecological resilience, proposed by (Medeiros and Torezan, 2012) and (Graciano-Silva et al. 2018), in which they presented Biotic Integrity indices for the sustainability of urban forests.

With the proposed adaptations, the Calculation of the Ecological Integrity Index of Eastern Cariri (ICECO) was formulated, all correlated with local vulnerabilities and considering two axes: biodiversity and climate.

$$\text{ICECO} = \text{Weight 1} \cdot \text{VC} + \text{Weight 2} \cdot \text{CV} + \text{Weight 3}$$

(formula from the study proposal)

Where:

- ICECO = Ecological Integrity Index of Eastern Cariri
- VC = Vegetation Cover (weight 0–1)
- CV = Climate Vulnerability (weight 0–1)
- RE = Ecological Resilience (weight 0–1)
- P1=0.6 ,P2=0.2 ,P3= 0.2 = Weights assigned to each axis (must total 1)

#### **2.1 Tools Used**

The following tools were used for this work: QGIS 3.34: with spatial processing of satellite images, segmentation and classification, as well as fragmentation metrics; R Studio (raster packages, ecolTools): statistical analysis. The raster package (applied with Rstudio) enables numerous GIS operations. Map algebra operations can be applied pixel by pixel (Mas et al. 2019).

#### **2.2 Social Analysis and Environmental Justice**

The region of Cariri Oriental Paraibano has characteristics and factors that point to a strong dependence on public policies and social assistance. These municipalities are part of areas with low population density and economic

vulnerabilities, hence the need for income transfer programs, such as Bolsa Família, and other social benefits (PAN-BRASIL, 2005).

According to PAE-PARAÍBA (2024), the most relevant social programs are: Water Supply Programs (water mains and water trucks); the State Government's Popular Restaurants Program, "Tá na Mesa" (It's on the Table), and Harvest Guarantee. In summary, according to IBGE (2010) and (2023), Table 1 presents the indicators for the three municipalities under study, Alcantil, Barra de Santana, and Riacho de Santo Antônio, demonstrating their social and economic dependence on the government.

Table 1 – Sample of social indicators for the three municipalities studied.

Indicators	Alcantil	Barra de Santana	Riacho de Santo Antônio
<b>HDI (Municipal Human Development Index)</b>	~0.500 (low index)	~0.540 (low index)	~0.550 (low index)
<b>Poverty index (%)</b>	High	High	High
<b>Access to drinking water (%)</b>	Low	Low	Low
<b>Solid waste collection (%)</b>	Low	Low	Low
<b>Basic sanitation (%)</b>	Below 50%	Below 50%	Below 50%
<b>Dependence on government programs</b>	High	High	High

Source: Author (2025); IBGE (2010, 2023).

### 3. Results and Discussion

To understand and comprehend the spectral behavior of vegetation through remote sensing, the following images were used:

- LANDSAT 8 OLI sensor with satellite pass: September 24, 2013, and November 17, 2023, the driest periods due to the presence of clouds and shadows in most of the months analyzed.
- Sentinel 2B MSI sensor with satellite pass: October 23, 2023, during a dry period, due to the presence of clouds in the preceding months.

The processing and all computational steps, using QGIS tools, were performed using the SCP > Pre-processing > DOS> start images plugin for atmospheric correction, followed by the step of cropping the municipal areas of interest using the VECTOR and RASTER menu tools for editing the crop.

The cloud mask was possible, considering the information from the additional add-ons of the image download platform, Copernicus Browser, as it brought images with cloud masks, facilitating spectral processing. Next, the MSI images were selected, the red (band 4) and infrared (band 8A) channels, and the OLI (band for the composition and definition of the Normalized Difference Vegetation Index, IVDN, studied and proposed by Rouse et al. (1973).

Considering its equation adjusted for Eastern Cariri, the equation was defined representing the period from 2012 to 2023, and the images that best suited the NDVI analysis were those from the Sentinel satellite, passing on October 2, 2023, during the dry season, but with small cloud spots, and those from OLI (Landsat8), passing on 07-11-2013, since the satellite had not been launched in 2012.

$$IVDN = (NIR5 - RED4) / (NIR5 + RED4) \quad \text{eq1}$$

Where:

NIR: near infrared, with a nanometric range corresponding to channel 5 (OLI sensor) and channel 4 (OLI sensor) corresponding to red.

For use with Sentinel, the equation was adapted as follows:

$$IVDN = (NIR8A - RED4) / (NIR8A + RED4) \quad \text{eq2}$$

In which, for the band corresponding to the 8A nanometric band, it is more suited to a reflectance that amplifies the observation of vegetation, as it is the edge infrared. And for red, channel 4 was used.

Analyzing the IVDN corresponding to 2013, Figure (2), it can be seen that for the three municipalities observed, and following the spectral behavior of the dry season, with the passage of the satellite in November 2013, the ranges of values between (0.36 – 0.56) reflect vegetative fragility in the middle of the dry season for the municipalities studied, noting a sensitivity in vigor due to possible anthropic activities in the areas, associated with high temperatures for this season, with low rainfall records. The local fragility corresponds to a prolonged drought, indicating a direct dependence of the vegetation on rainfall, which influences the result of the IVDN analyzed.

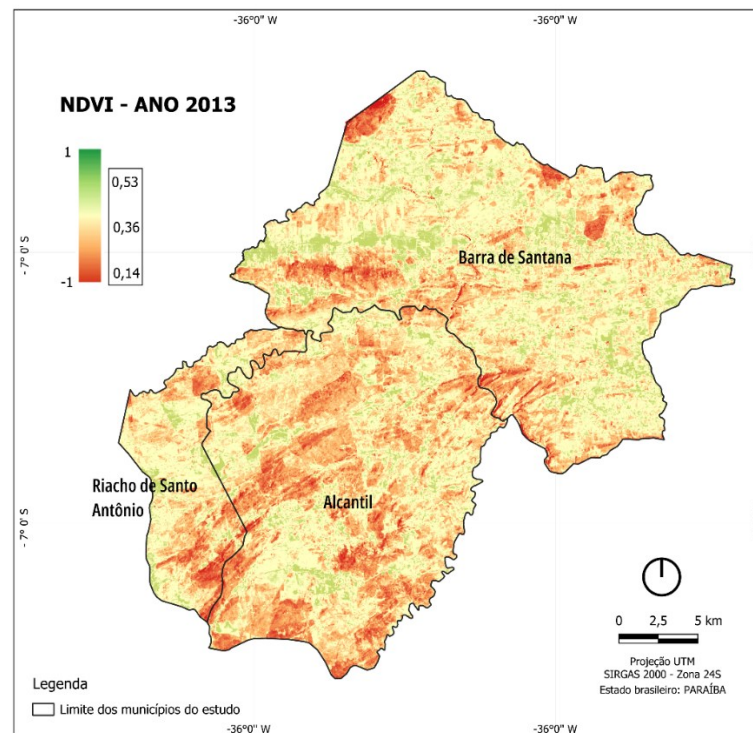


Figure 2– Analysis of IVDN 2013, for evaluation of vegetative behavior.  
Source: QGIS 3.34 (2025).

For the year 2023, the temporal and spectral reality of the NDVI information for 2023 shows a reality that is not so distant, with regard to a prolonged drought that occurred between 2012 and 2017, one of the worst ever recorded, due to the presence of El Niño (CGEE, 2016). The ranges (0.38–0.62) reflect a certain recovery of native vegetation cover, more precisely in the municipalities of Barra de Santana, near the Paraíba River, as well as in areas with less anthropic access in the three municipalities. It is worth noting that the stretch of the Paraíba River runs through the waters of the São Francisco River, with the course flowing from Boqueirão to the Acauã reservoir in Itatuba. According to the spectral characteristics of the vegetation, the green color is accentuated due to the previous months of 2023 having been rainier, as can be seen in Table 2, which shows precipitation. However, anthropic activities linked to poor land use, due to the various agricultural activities in these municipalities, as can be seen from the analyzed IVDN average, indicate that the area is still limited and resilient, meaning that there are still weaknesses that may be prolonged or gradually affected.

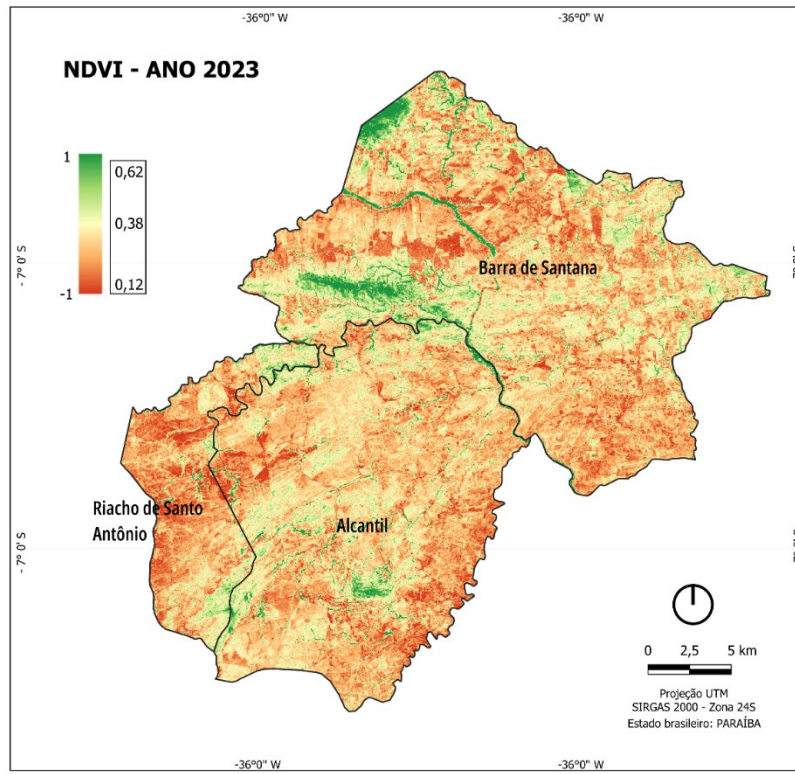


Figure 3 - Analysis of IVDN 2023, for evaluation of vegetative behavior.  
Source: QGIS 3.34 (2025).

The behavior of native vegetation changes or is filled in during rainy periods, which was not the case in this analysis, as it considers the dry period. Environmental degradation can be “masked” because we consider that in this semi-arid region, pastures, small trees, and shrubs predominate in large numbers, thus seeing the need for further analysis of this Caatinga biomass. To analyze in more detail, considering a small classification of vegetation, called the forests of Eastern Cariri, it was possible to analyze using the LecoS plugin, from QGIS3.34, together with the statistical application of the R studio library-dplyr and Library-ggplot2, to complement the tabular and graphical data. The metric considered was obtained using the following tools: Raster > landscape statistics > and then Landscape Proportion and the average per class, in this case considering only (fragments of dense vegetation, which may be trees, and semi-dense vegetation, which may be shrubs or cacti). The averages in m<sup>2</sup> were converted to km<sup>2</sup> in QGIS.

According to studies by Costa Filho et al. (2008), when studying areas in Rio Grande do Norte, most of the areas that are mixed with the process of urbanization and anthropic activities are composed of vegetation such as catingueira (*Poincianella bracteosa*) and other species such as pereiro (*Aspidosperma*), a situation similar to the areas studied in this work. With the data already acquired by the software and monitored by R, in Table 2, the metric values can be considered and identified through the classifications generated by the software. The fragments of native forests in Eastern Cariri were counted according to the area generated by the fragments, considering the years 2013 and 2023. Figure 4 shows the aforementioned results of the fragments found in the municipalities studied, Alcantil, Barra de Santana, and Riacho de Santo Antônio.

Table 2: Values of fragments generated by the metric, by vegetation class (2013).

Year	Municipality	Class	Area (km <sup>2</sup> )	N° of Fragments	Average Area (km <sup>2</sup> )
2013	Barra de Santana	Dense Vegetation	0	0	0
2013	Barra de Santana	Semi-dense Vegetation	63.589	9,852	0.00646
2013	Alcantil	Dense Vegetation	0	0	0
2013	Alcantil	Semi-dense Vegetation	59.800	8,958	0.00668
2013	Riacho de Santo Antônio	Dense Vegetation	0	0	0
2013	Riacho de Santo Antônio	Semi-dense Vegetation	7,541	421	17.91188

Source: Author (2025).

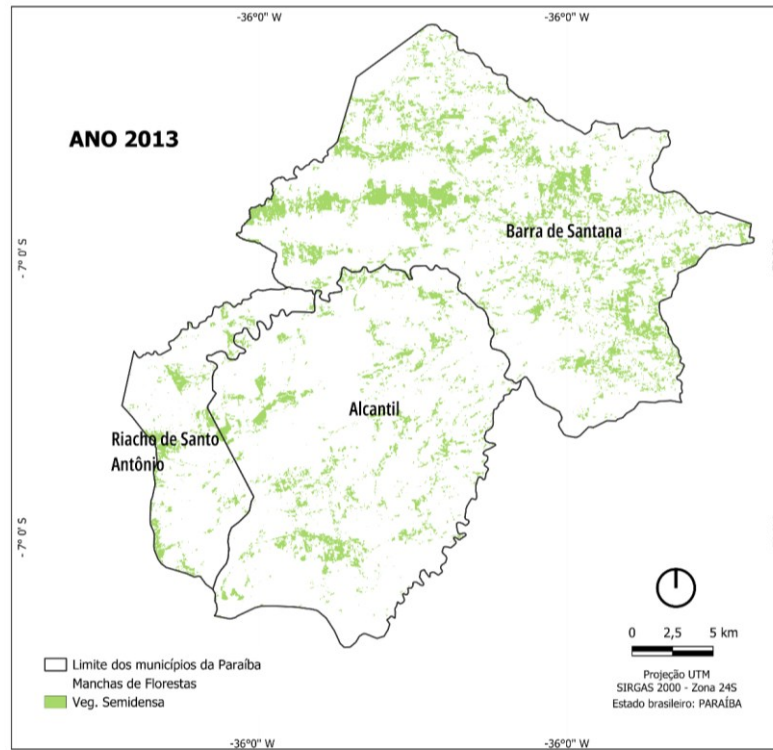


Figure 4 - Thematic model of patches considering the term forests for the three municipalities of Eastern Cariri. Source: QGIS (2025).

Table 3: Values of fragments generated by the metric, using vegetation classes.

Year	Municipality	Class	Area (km <sup>2</sup> )	N° of Fragments	Average Area (km <sup>2</sup> )
2023	Barra de Santana	Dense Vegetation	47.233	4,623	0.01022
2023	Barra de Santana	Semi-dense Vegetation	33.952	4,852	0.00700
2023	Alcantil	Dense Vegetation	48.123	8,452	0.00569
2023	Alcantil	Semi-dense Vegetation	29.874	6,854	0.00436

2023	Riacho de Santo Antônio	Dense Vegetation	5.468	562	0.00973
2023	Riacho de Santo Antônio	Semi-dense Vegetation	4.987	236	0.02113

Source: Author (2025).

The stain tool clearly showed a striking reality for the three municipalities, as can be seen in Tables 2 and 3. For the year 2013, there is an ecological disconnect due to the fact that the fragments are more isolated or broken, justifying the intense anthropic actions in search of water, and agro-pastoral, livestock, and animal transport work. Considering the year 2023, and observing the previous conditions of the analyzed fragmentations, there was a small increase in semi-dense vegetation, a situation that puts the municipalities under observation due to the fact that this condition is associated with an increase in pastures and possible reductions in native forest over the years and, consequently, a reduction in the region's native fauna and flora. However, vegetation metrics show that the largest fragments are able to achieve a state of better ecological potential, although the biophysical conditions of the municipalities must be considered.

Figure 5 shows the classes associated with the average values, all of them, for the three municipalities, well below 1.0 km<sup>2</sup>, showing that they may or may not cause biodiversity loss , amid records of droughts and high temperatures.

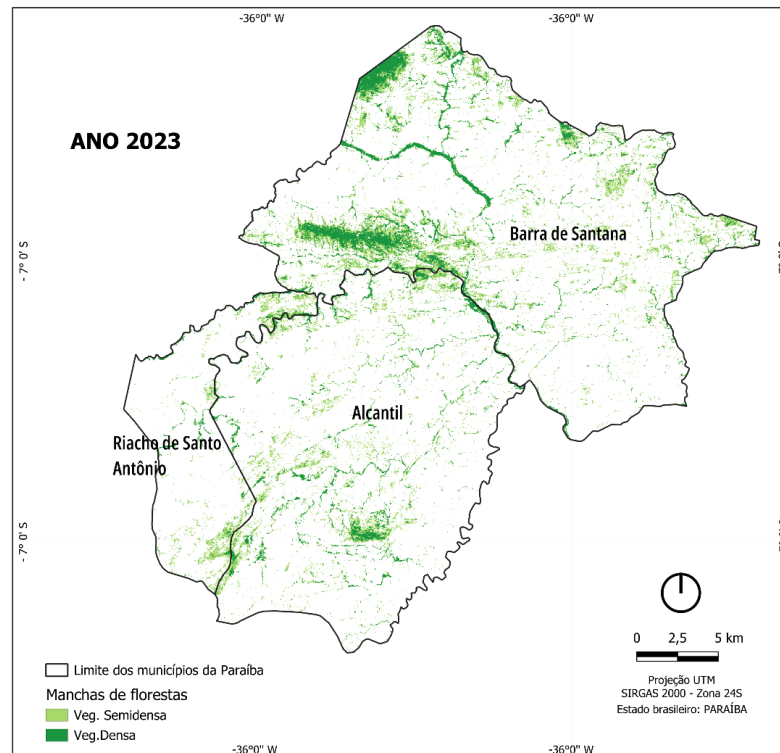


Figure 5 – Thematic model of patches considering the term forests for the three municipalities of Eastern Cariri. Source: Author (2025); Specific data from MapBiomias (2023).

### 3.1 Climate Vulnerability

The analysis of the rainfall regime in the three municipalities considered a cross-reference between temperature conditions and local rainfall. For the municipality of Alcantil, over the last 12 years, there has been intense variability in precipitation, with 2016 standing out for reaching an annual average of 200 mm, a severe and extreme condition, while in

2022 it reached a significant average of 550 mm (AESA, 2023). According to Table Z, the average annual temperatures between 2013 and 2023 show that temperatures until 2022 fluctuated between 24.4 and 25.8°C, but in 2023, the reality of the temperature began to change, showing an increase to 25.9°C. The years analyzed, considering the temperature and prolonged droughts, caused great water stress and a gradual process of vegetation degradation, which consequently points to the fragility of forest fragmentation and biodiversity loss. In the case of Barra de Santana, according to AESA (2023), rainfall also showed irregularities over the 10-year period. However, in 2022, precisely because of the irregular atmospheric cycles, there was a peak rainfall of more than 700 mm. At the height of the severe drought, between 2025 and 2027, the annual rainfall was just under 250 mm. Temperatures averaged between 24.9°C and 25.7°C, showing a gradual increase, especially in the last two years, 2022 and 2023.

This atmospheric and meteorological behavior, combined with anthropogenic activities, further compromises the regenerative power of vegetation cover and consequently leads to the loss of flora and fauna species, a situation similar to the diagnosis studied by Souza (2008) in Cariri, Paraíba, where intense rural activities compromised the composition of the tree and shrub layer in the studied region, in Cabaceiras-PB.

The municipality of Riacho de Santo Antônio, also located in a region of high climate vulnerability, experienced an increase in rainfall in 2022, which, according to AESA (2023), were the best months of rainfall for Cariri, Paraíba. However, the strength of the El Niño phenomenon and other atmospheric conditions between 2015 and 2016 were extremely severe for the municipality, registering only 150 mm. The most notable temperature records, as shown in the graph in Figure 6, show a considerable increase in 2023. Figure 7 summarizes the annual average, which already shows the increase starting in 2022. The fragmented areas of this municipality were evident in the vegetation cover, and high temperatures further reduce the local flora. These conditions of degradation in the municipality studied are not so recent, given that the years 2012 to 2023 were punishing in terms of losses of vegetation and local animal species. According to Silva (2012), the aridity index record for the municipality of Riacho Santo Antônio, in its climate assessment, was classified as very severe and within an arid zone.

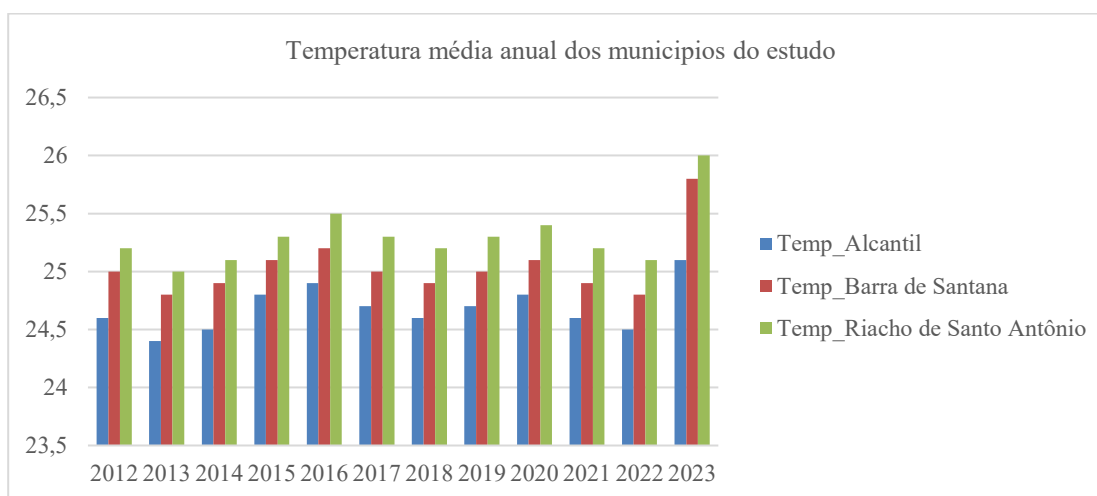


Figure 6 – Graph showing average temperatures in municipalities in Eastern Cariri. Source: AESA (2023).

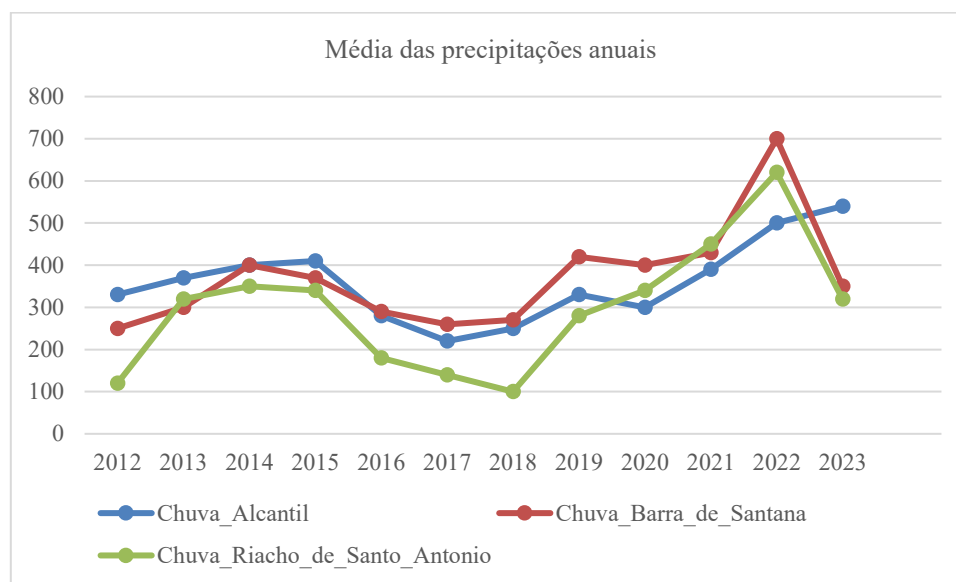


Figure 7 – Annual average rainfall in the municipalities of Eastern Cariri. Source: AESA (2023).

The climatic conditions and their changes over the more than 10 years analyzed show that the three municipalities are part of a climatic regime that directly affects biodiversity, distorting the native landscapes of the Cariri ecosystem, amid constantly fluctuating temperatures, especially during periods of severe drought. The index proposed in this study, the Eastern Cariri Ecological Integrity Index (ICECO), correlates biodiversity and climate with the processes involved in the loss of habitat and green areas in the municipalities. Using the R packages and consulting the library: (library (landscapemetrics), library (dplyr), library (ggplot2) to organize the information via script, the information was associated considering the fauna and flora of the three municipalities, a situation that, according to the authors Lima; Barbosa (2014), Barbosa et al. (2007), Araújo (2012), several species and forest wealth, according to scientific surveys and research, contributed to identifying more than 400 species of native plants, the most frequent being (Leguminosae, Euphorbiaceae, Asteraceae, Malvaceae, and Cactaceae) and native animals with birds and reptiles, with 218 bird species standing out (Northeastern Goldfinch *Spinus yarrellii* and endemic species), (Zanetti, 2023). Integrating this ecosystem condition linked to fauna and flora, local biodiversity, of the three municipalities, and based on the assigned metric and NDVI, using QGIS3.34 software, the three axes: Vegetation Cover (VC), Climate Vulnerability (CV), and Ecological Resilience (ER) with the weights assigned according to their ecological relevance ( $P1 = 0.6$ ;  $P2 = 0.2$ ;  $P3 = 0.2$ ), using R (junction: raster, landscapemetrics), the results of  $(ICECO=(VC \times P1)+(VC \times P2)+(RE \times P3))$  indicated for the three municipalities, as shown in Table 4:

Table 4: Results of the Ecological Integrity Index for Eastern Cariri.

Source: Prepared by the author (2025), adapted from Acuña-Alonso et al. (2021);

Municipality	CV	VC	RE	ICECO
Alcantil	0.50	0.70	0.60	0.48
Barra de Santana	0.80	0.40	0.75	0.75
Santo Antônio do Cariri	0.65	0.60	0.70	0.65

(Graciano-Silva et al. 2018).

The results indicate that, according to IVDN data associated with metric fragmentation, over the 10-year period, the municipality of Alcantil, with an ICECO = 0.48 and small fragments (< 0.01 km<sup>2</sup>), generates favorable conditions for the edge effect, reducing internal habitats, but may cause damage to more sensitive species. This reflects precisely the high climate vulnerability (0.70). For the municipality of Barra de Santana, ICECO = 0.75, the latest rainfall records, associated with lower vulnerability in areas with IVDN between (0.62), already demonstrate better adaptability of native species (fauna and flora) to remain in the environment, even with the climatic effects of high temperatures. The ICECO performance for the municipality of Riacho de Santo Antônio was intermediate, with 0.65, showing that fragmentation compromises fauna, but there is potential for recovery, as vegetation cover helps to balance and address climate vulnerability.

### Final Considerations

The semi-arid region of Paraíba is characterized by climatic instability and, at the same time, a resilient ecosystem, in which climate change puts survival strategies “into play,” attempting to connect with the rainfall regime (strong or weak) to adapt for better survival. The tools used in this study to construct the ICECO proved to be highly effective in understanding the ecological state and condition with regard to climatic phenomena, showing that it should be used to support conservation and environmental management plans, as well as socio-environmental justice.

The IVDN and metric data, together with meteorological data, showed that there is no full Ecological Integrity of Eastern Cariri in the municipalities of Alcantil, Barra de Santana, and Riacho de Santo Antônio, as there is a disconnect between the fauna and flora, as low vegetation cover compromises and hinders the ecological state and generates risks of biodiversity loss, as they are overly exposed to high temperatures. The cross-referencing of geospatial, rainfall, and fragmentation data reinforces the need for environmental policies more focused on the preservation and closure of areas more sensitive to intense anthropic activities.

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