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EVOLUÇÃO HISTÓRICA DE ANOMALIAS DE CHUVA E ARIDEZ NO SEMIÁRIDO: O CASO DO MUNICÍPIO DE CRATEÚS, CEARÁ

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RESUMO: A região dos Inhamuns, no sertão do Ceará, caracteriza-se por um clima semiárido, marcado por uma alta variabilidade pluviométrica e frequentes períodos de seca. Este estudo tem como objetivo analisar a evolução histórica das anomalias de chuva e do índice de aridez na região, considerando o impacto das variações climáticas e dos fenômenos naturais sobre a dinâmica da precipitação ao longo das últimas décadas. Foram utilizados dados históricos de precipitação e temperatura para calcular o índice de aridez de Thornthwaite, a fim de traçar a evolução desses parâmetros no contexto das mudanças climáticas. Os resultados indicam um aumento na frequência de anomalias de chuva e uma intensificação dos períodos de aridez, o que reflete a vulnerabilidade da região às oscilações climáticas e ressalta a importância de estratégias de adaptação e mitigação.

Palavras-chaves: IAC, Índice de Aridez, Mudanças climáticas.

HISTORICAL EVOLUTION OF RAINFALL ANOMALIES AND ARIDITY IN THE SEMI-ARID REGION: THE CASE OF CRATEÚS, CEARÁ

ABSTRACT: The Inhamuns region, in Ceará, is characterized by a semiarid climate characterized by high rainfall variability and frequent droughts. This study aims to analyze the historical evolution of rainfall anomalies and the aridity index in the region, considering the impacts of climatic variations and natural phenomena on precipitation dynamics over recent decades. Historical precipitation and temperature data were used to calculate the Thornthwaite aridity index, mapping the evolution of these parameters in the context of climate change. The results indicate an increase in rainfall anomalies and intensified aridity periods, highlighting the region's vulnerability to climate fluctuations and underscoring the importance of adaptation and mitigation strategies.

Keywords: RAI, Aridity index, Climate Change.

1 INTRODUCTION

Drought is a dominant climatic phenomenon in northeastern Brazil, resulting from the uneven distribution of rainfall in time and space (Sousa, 2023). This scenario makes rainfall monitoring essential, especially in semiarid regions such as Inhamuns, Ceará, where water availability depends directly on the level of rivers and reservoirs, which are essential for local supply.

In Inhamuns, the semiarid climate combines low average annual precipitation and high variability, with concentrated rainfall alternating with long droughts. This pattern highlights the importance of studying precipitation anomalies and aridity conditions to understand their effects on water availability and agricultural resilience (Aderaldo; Amorim; Nery, 2023).

To assess aridity and water restriction, the aridity index (AI), which is calculated from the relationship between precipitation and potential evapotranspiration (PET) and reflects the level of environmental dryness, is widely used. In addition, the rainfall anomaly index

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(IAC) is a key indicator for analyzing changes in the precipitation regime, facilitating temporal comparisons (França *et al.*, 2020; Jarrar *et al.*, 2023).

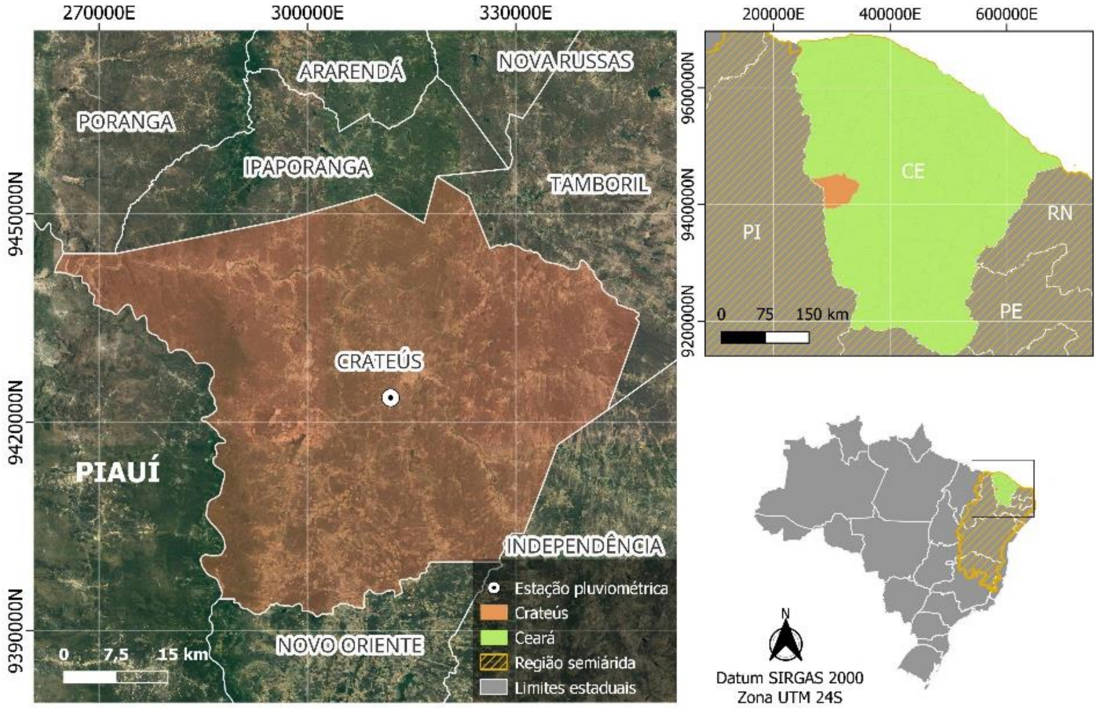
This study, therefore, aims to identify the temporal variation in the aridity index and the rainfall anomaly index for the municipality of Crateús in the semiarid region of Ceará.

2 MATERIALS AND METHODS

2.1 Study area

The study focuses on Crateús in the Sertão dos Inhamuns region of Ceará (Figure 1), which encompasses 16 municipalities covering 26,227.3 km², representing 17.6% of the state's territory. With a population density of 15.7/km², below the state average of 55.2/km², the cities of Crateús and Tauá are the main service centers. The average annual precipitation in Crateús is 600 mm, concentrated from January to April, with a potential evapotranspiration of 1,900 mm and an average temperature of 28°C (INMET, 2024).

Figure 1. Locations of the study area and the rainfall stations.



Source: Authors (2024)

2.2 Data collection

To analyze the evolution of rainfall and aridity anomalies, rainfall and temperature data were collected from the Inhamuns region at a station in Crateús (Table 1).

Table 1. Data from the meteorological station used to calculate the indices.

Code	Operator	Period Temperature	Precipitation Period	Lat.	Lon .
540020	DNOCS/FUNCEME	1963 to 2018	1911 to 2023	-5.210	-40.703

Source: Authors (2024)

2.3 Aridity index (AI) and rainfall anomaly index (RAI)

The aridity index (AI, Eq. 1), which is based on the Thornthwaite equation (1948), uses precipitation and potential evapotranspiration data to classify the climate and identify aridity trends, standing out for its use of quantitative variables and applicability to dry environments.

$$IA = \frac{P}{ETP} \quad (1)$$

where P = total annual precipitation (mm) and ETP = annual potential evapotranspiration (mm).

Matallo Júnior (2003) proposed a climate classification for various climates on the planet that assists in the analysis of susceptibility to desertification, as illustrated below.

Table 2. Classification of susceptibility to desertification according to the aridity index.

Class	Dryness Index (AI)
Wet	> 1.0
Humid subhumid	0.66 – 1.0
Dry subhumid	0.51 – 0.65
Semiarid	0.21 – 0.50
Arid	0.03 – 0.20
Hyperarid	< 0.03

Source: Authors (2024)

The ETP was obtained via the formula proposed by Thornthwaite (1948), which considers the average temperature (T) and a correction factor (α) that varies according to the season. The ETP is calculated as:

$$ETP_{mês} = 16 \cdot \left(\frac{10 \cdot Tm}{I}\right)^{\alpha} \quad (2)$$

where ETP = potential evapotranspiration (in mm); T_m is the average monthly temperature in °C; and I is the annual heat index, which depends on temperature and is calculated as the sum of the monthly indices:

$$I = \sum_{i=1}^{12} \left(\frac{T_{m,i}}{5}\right)^{1,514} \quad (3)$$

The term α is an empirical coefficient dependent on I and is calculated as:

$$\alpha = 6.75\times10^{-7} \cdot I^3 - 7.71\times10^{-5} \cdot I^2 + 1.79\times10^{-2} \cdot I + 0.49239 \quad (4)$$

The calculated monthly ETP is adjusted by a factor that considers the mean day length, which reflects seasonal and latitudinal variations in solar radiation. This adjustment is included in the parameter α, which is fundamental for the estimation of ETP according to Thornthwaite (1948).

To analyze the frequency and intensity of dry years according to the local average, the temporal averages of precipitation for the period 1911--2023 were calculated via the Rainfall Anomaly Index, which was developed and tested by Rooy (1965). This index is less complex than the other indices and is based only on rainfall data. For this study, the following equations adapted for Northeast Brazil by Freitas (1998) were used.

$$IAC = 3 \cdot \left[\frac{N-\bar{N}}{M - \bar{N}}\right] \quad (5)$$

$$IAC = -3 \cdot \left[\frac{N-\bar{N}}{X - \bar{N}}\right] \quad (6)$$

where N represents the observed annual precipitation (mm); $\bar{N}$ represents the average annual precipitation of the historical series (mm); M represents the average of the ten highest annual precipitation values of the historical series (mm); and X represents the average of the ten lowest annual precipitation values of the historical series (mm). Positive anomalies (Eq. (5)) are values above the average, and negative anomalies (Eq. (6)) are below the average; their classification can be assessed according to Table 3 (Araújo; Moraes Neto; Sousa, 2009).

Table 3. Classification of susceptibility to desertification according to the aridity index.

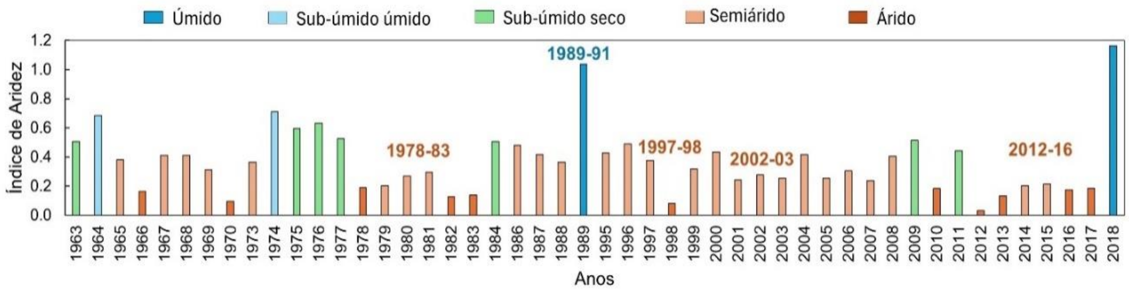
Rainfall Anomaly Index (RAI) Range	Intensity classification
> 4	Extremely humid
2 to 4	Very humid
0 to 2	Wet
- 2 to 0	Dry
- 4 to -2	Very dry
< - 4	Extremely dry

Source: Authors (2024)

3 RESULTS AND DISCUSSION

The analysis revealed that during the rainy season (January to April), significant variation was observed: in January, evapotranspiration was high due to the response of dry soils to the first rains, but it gradually declined until April, probably due to soil saturation and increased humidity, reducing water loss (Freire; Lima; Cavalcanti, 2011). The AI analysis indicated a predominance of semiarid (27 occurrences) and arid (11 occurrences) conditions, with most AI values between 0.05 and 0.50, characterizing the arid climate of the region and indicating recurring water scarcity. Figure 2 illustrates this classification throughout the study period.

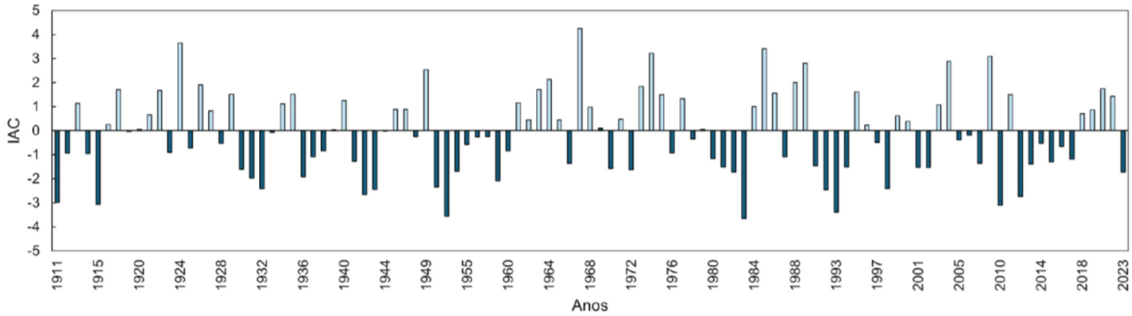
Figure 2. Historical aridity index for Crateús; highlighting periods of historical droughts (brown font) and floods (blue font).



Source: Authors (2024)

The years classified as wet (1989 and 2018) are possibly explained by global climate phenomena such as El Niño, which intensifies rainfall in Northeast Brazil (Costa, 2012). In contrast, years of extreme drought, classified as arid or hyperarid, intensify local water and socioeconomic vulnerability, highlighting the importance of constant monitoring to mitigate impacts on agriculture and water availability. Cavacante (2023) mentioned water works in the Inhamuns backlands promoted by the Emergency Program during the 1978--1983 drought. Figure 3 illustrates dry and wet periods between 1911 and 2023, highlighting moments of greater intensity and duration.

Figure 3. Rainfall anomaly index for the municipality of Crateús



Source: Authors (2024)

Positive IAC values represent wet years, whereas negative values indicate dry years. In the total period, there were 47 years of positive IAC and 65 years of negative IAC, indicating regional climate variability. In the first quartile (1911--1938), wet years predominated slightly (15 years with positive IAC values versus 12 dry years), reflecting a balance but still with great alternations between rainy and dry periods. In the period between 1967 and 1994, a slight change was observed with 12 wet years and more intense anomalies, with the extreme value of 4.25 in 1967 standing out, indicating an exceptionally rainy year and probably associated with atmospheric conditions that favored intense rainfall, with possible implications for water recharge and risk of flooding and erosion (Araújo; Moraes Neto; Sousa, 2009).

4 CONCLUSIONS

Analysis of rainfall anomalies and the aridity index in the Inhamuns region indicates an intensification of arid conditions and climate variability. The correlation between El Niño and La Niña events and precipitation dynamics highlights the importance of climate monitoring and adaptation strategies to reduce the impacts of climate change. Measures such as efficient water resource management, sustainable agricultural practices, and public policies aimed at mitigating the effects of droughts are essential for regional resilience.

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