

# **Spatial And Temporal Comparison Of Agricultural Production In The Semi-Arid Region Of Brazilian Ceará State, Based On The 1995/1996, 2006 And 2017 Agricultural Censuses**

Jose De Jesus Sousa Lemos<sup>1</sup>, Milena Monteiro Feitosa<sup>2</sup>,  
Elizama Cavalcante De Paiva<sup>3</sup>, Erika Costa Sousa<sup>3</sup>,  
Jamile Ingrid De Almeida Salviano<sup>3</sup>

<sup>1</sup>(Professor In Post Graduation Program Of Agricultural Economics. Department Of Agricultural Economics, Federal University Of Ceará (UFC), Brazil)

<sup>2</sup>(Phd Student In Program Of Desenvolvimento E Ambiente At Federal University Of Ceará (UFC), Brazil)

<sup>3</sup>(Phd Student In Agricultural Economics At Federal University Of Ceará (UFC), Brazil)

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## **Abstract:**

*The study evaluated the synergy between rainfall and indicators of vegetation cover, land productivity and wealth generation in the rural sector of municipalities in the semi-arid region of Ceará. Data from the 1995/96, 2006 and 2017 Agricultural Censuses were used. The study also sought to assess the behavior of Ceará's climatic regions with regard to rainfall. Rainfall data was collected from the Ceará Foundation for Meteorology and Water Resources (FUNCEME), and information on vegetation cover, land productivity in crop and animal production was collected from the 1995/96, 2006 and 2017 IBGE Agricultural Censuses. Information on the GDP of the municipalities was also sought from other IBGE documents that publish this information. The study created the agricultural production preservation index (IPPA), which was used to capture the synergy between the indicators. Factor analysis was used for this purpose. The results found served to answer the guiding question of the research, which was to assess the synergy between rainfall and the other variables. It also showed that the climatic regions of Ceará presented different average values and instabilities, with the region with the greatest climatic difficulties being the Sertão Central and Inhamuns. The results showed that 1996 had the best rainfall levels and the highest IPPA values compared to 2006 and 2017. Therefore, there was an interaction between rainfall and preservation indicators applied in the semi-arid region of Ceará during the study period.*

**Key Word:** *Agricultural production; Northeast region. Funceme; Vegetation cover; Rainfall distribution patterns.*

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## **I. Introduction**

Agricultural production in the Northeast region of Brazil faces major obstacles associated with a complex synergy of factors that contribute to the depletion of the region's natural resources and make it difficult, or even impossible, to produce agricultural goods in most of the municipalities of the nine states that comprise it. In Ceará State, the situation is not very different, given that the levels of productivity achieved by agricultural and pastoral activities are very low. This is possibly due to the still low technological standard in which agricultural and livestock activities are practiced in the state. The cumulative impact of centuries of inadequate exploitation of these activities has drastically reduced not only the production and productivity of the land, but has also contributed to the loss of resilience of agricultural production systems to the water stresses to which the state is cyclically subjected (CEARÁ, 2010).

Ceará currently has 175 of its 184 municipalities officially recognized as belonging to the semi-arid climate (SUDENE, 2024). In this state, it is clear that, in addition to the vulnerabilities imposed by the irregular rainfall of the semi-arid region that prevails in practically its entire geographical area, a very significant part of the soil is degraded and its vegetation cover is seriously compromised (Ferreira, 2015).

In the semi-arid region of Ceará, rainfall is intermittent, both in terms of space and time. Between 2012 and 2016, the state, like the entire Northeast region, experienced a long period of drought that had significant repercussions on plant production, animal husbandry, vegetation cover, fauna diversification, and the replenishment of underground aquifers (mainly the water table) and surface water, including reservoirs built for water storage.

In addition, temperatures in the state are high and air humidity is low (FUNCEME, 2020). The soils are shallow and, in general, have low natural fertility. Furthermore, in considerable parts of the state's surface, crystalline rock outcrops can be observed. Crystalline shields, or ancient massifs, are a type of very resistant geological formation that are usually found in low-altitude areas. They consist of metamorphic and magmatic crystalline rocks, which are highly resistant to erosion and weathering. The vegetation cover characteristic of the semi-arid region of Ceará, as well as that which prevails in this climate zone in Brazil, is the caatinga. This cover has been severely degraded by human activities, namely predatory agriculture practiced by both family farmers and large-scale farmers.

Another factor contributing to the collapse of the regional and state caatinga is the removal of vegetation cover for use as firewood or charcoal, which are used for cooking food in rural homes, most of which are very poor, or for burning in furnaces in bakeries and potteries, in many cases located far from the areas where the vegetation is removed (BRASIL, 2005; Lemos, 2020).

This synergy between anthropic actions and nature means that the semi-arid region of Ceará has levels of preservation of its productive capacity in difficult situations, also due to the geographical diversity of the state, which also has some additional aggravating factors in the spatial and temporal heterogeneities of rainfall distribution. Due to this asymmetry in rainfall distribution, Xavier (2001) conducted a study that identified eight macroregions with different but intrinsically homogeneous rainfall distribution patterns. Research conducted by Salviano in 2021, which evaluated rainfall for the period from 1974 to 2019, confirmed this classification, which is shown in Table 1 and Figure 1.

| Table no 1: Climate regions created by Xavier for the state of Ceará |                          |
|----------------------------------------------------------------------|--------------------------|
| Climate regions                                                      | Number of municipalities |
| Cariri                                                               | 28                       |
| Ibiapaba                                                             | 26                       |
| Jaguaribana                                                          | 24                       |
| Fortaleza Coastal                                                    | 14                       |
| Pecém Coastal                                                        | 16                       |
| North Coastal                                                        | 22                       |
| Baturité Massif                                                      | 14                       |
| Central Hinterland and Inhamuns                                      | 40                       |
| TOTAL                                                                | 184                      |

Source: XAVIER, T. M. B. S, 2021

Growing rainfed crops depends directly on rainfall conditions. Fluctuations in the development of rainfed crops are mainly due to climatic variability, especially rainfall. They are therefore high-risk activities. The weaknesses of this production system are reflected in variations in harvested areas, yields, prices, and incomes associated with these activities. For these reasons, farmers are left to develop adaptive capacities as defense mechanisms (Bezerra, 2022; Costa Filho, 2019; Fischer et al., 2002; Lessa, 2023; Lemos, Bezerra, 2023; Lessa et al., 2023; Sousa et al., 2023).

Figure 1 – Map of Ceará with the 8 regions identified



Source: SALVIANO, 2021.

According to Fischer *et al* (2002), rain-fed agricultural crops, for most family farmers, depend on the availability of natural resources. Crops such as beans, cassava, and corn, which are grown by family farmers under this regime in the states located in the semiarid region, are heavily dependent on the spatial and temporal distribution and, ultimately, the instability of rainfall, which is the norm in the semiarid region (FUNCEME, 2020; Lemos, 2020).

In view of the above, this research attempts to answer the following question: Is there synergy between rainfall and indicators of vegetation cover, land cover, and income generation in rural areas of municipalities in Ceará officially recognized as part of the Brazilian semi-arid region? In seeking to answer this question, the research has the following objectives: a) To estimate the averages and levels of rainfall instability in the eight (8) climatic regions into which Ceará is divided; b) To assess how indicators of vegetation cover, land productivity, and the relative share of the rural sector's GDP in the aggregate GDP of the municipalities interacted with rainfall in these municipalities according to the 1996, 2006, and 2017 Agricultural Censuses; c) To develop a scale for defining the productive capacities of these municipalities in each year.

## **II. Concepts Involved In The Research**

The research works with the concepts of preservation of productive capacity in the rural sector and its negation, which is environmental degradation, as theoretical anchors for the selection of indicators and for the construction of the instrument that was used to assess how plant, animal, and agricultural production in general evolved in the municipalities of Ceará officially recognized as part of the semi-arid region of the state of Ceará in the records of the 1995/96, 2006, and 2017 Agricultural Censuses.

### **Environmental degradation**

The term environmental degradation is recurrent in technical literature, but not only there. According to Brazilian Law No. 6,938, dated August 31, 1981, which established the National Environmental Policy, Article 3, item II, the following concept was established: "environmental degradation is the adverse alteration of the characteristics of the environment" (BRAZIL, 1981).

Environmental degradation implies its destruction, causing a potential reduction in the availability of productive assets as a result of a synergy of events acting on natural and environmental resources such as air, water, soil, and ecosystem deterioration. If not stopped, it makes life unviable in environments with such characteristics (Choudhary *et al.*, 2015; Lal, 2015).

In the long term, there is a reduction in the diversity of natural vegetation and wildlife, salinization, and soil solidification. All these impacts can be caused or even induced by human action through deforestation, predatory agriculture, removal of vegetation cover for use as an energy source, incorporation of marginal lands into the agro-pastoral production process, incorrect irrigation, cultivation of large areas without proper diversification, use of fire as a means of clearing areas, among others.

Pollution from factory and vehicle emissions is also blamed for environmental degradation. In addition to this, another cause is the lack of or inadequate sanitation, which dumps waste into streams, creeks, rivers, and seas. The accumulation of solid waste that is not collected and/or properly treated and packaged (Lemos, 2020).

The result of the intersection of these factors is a process of depletion of natural resources, largely corroborated by global population growth, which, acting together, leads to increased environmental degradation, affecting its productive capacity for food and raw material production and the continued occupation of population contingents, especially in rural areas (Duque, 2001; Kazmierczak, Seabra, 2007; Choudhary *et al.*, 2015; Gama, 2016).

Environmental degradation leads to the impoverishment of ecosystems which, in the case of arid, semi-arid, and dry sub-humid areas, can contribute to the formation of desertification processes. Desertification is considered a continuous process of changes in soils, vegetation, and rainfall patterns which, due to environmental deterioration, can cause localized pressures on climatic factors and hinder the resilience of productive capacity in the rural sector (Bezerra, 2022; BRAZIL, 2016; Lessa, 2023; Malik *et al.*, 2014; Salviano *et al.*, 2020).

According to the Brazilian Agricultural Research Corporation (EMBRAPA), it is estimated that Brazil has between 60 and 100 million hectares of soil at various levels of degradation. In addition, this study indicates that more than half of the areas with pastures (cultivated or natural) are degraded (Bolfe, 2018).

In the Northeast, these problems are compounded by rainfall instability, both over the years (temporal) and within the same year (spatial). In fact, between 2010 and 2017, this region and Ceará, which is part of it, experienced a shortage of rainfall. During those eight years, the average rainfall in Ceará was only 546.4 mm, or 69% of the average observed for the state between 1950 and 2019. In 1996, the average rainfall in Ceará was 1064.10 mm. In 2006, it rained an average of 830.10 mm in Ceará, while in 2017, the average rainfall in the state was only 698.20 mm. In the Central and Inhamuns sub-region, which is made up of forty (40) municipalities, the average rainfall that year was 590.3 millimeters. This is undoubtedly the sub-region with the most rainfall problems in Ceará (FUNCEME, 2020; Salviano, 2021).

The interactions between these factors that cause degradation of the productive capacity of municipalities have a negative impact on land productivity in crop production and animal husbandry, making it difficult and often impossible to produce food and/or raw materials for the market.

These are generally small areas and, as they have to extract supplies for their families from them, they cultivate them to exhaustion and for years on end without giving them a break so that the areas can rest from cultivation and allow scrub to form, which would help to regenerate, at least partially, the vegetation cover.

In addition, the remaining vegetation cover is subjected to other severe impacts, resulting from its removal for use as firewood or charcoal, which will be used in homes for cooking food, or in the furnaces of industries of various sizes, often located far from the collection areas. In the semi-arid region, these problems are aggravated by the systematic occurrence of droughts. This means that material poverty induces people to use natural resources until they are exhausted. This contributes to the reduction of the productive capacity of environments in the semi-arid region (Serrano et al., 2015; Moura et al., 2025)

### **III. Material And Methods**

Rainfall data for municipalities was collected from the Ceará Foundation for Meteorology and Water Resources (FUNCEME). Information on agricultural production was obtained from the 1995/96, 2006, and 2017 Agricultural Censuses of the Brazilian Institute of Geography and Statistics (IBGE) for the state of Ceará. The aggregate Gross Domestic Product (GDP) of the municipalities for the years 1999, 2006, and 2017, provided by the IBGE, was also used. This is because the IBGE only began to publish the GDP of municipalities in 1999, which is why this will be the base period for comparison for this indicator.

The units of observation used are the municipalities of Ceará that existed in the three years studied and are included in the semi-arid region according to the latest Sudene report. It is worth noting that, according to the latest definition by the Development Council of the Superintendence for the Development of the Northeast (SUDENE), 175 of Ceará's 184 municipalities are now officially recognized as being in the Brazilian semi-arid region for the purposes of all public policies designed for this climate regime (SUDENE, 2021).

Since 1996, Ceará has had the same number of municipalities to this day (184 municipalities).

However, in 17 municipalities recognized as part of the semi-arid region, the indicators used in the study presented values that characterize them as outliers. For this reason, the observations from these municipalities were discarded. Thus, the study works with 168 of the 175 municipalities in Ceará that are included under this climate regime in the state.

#### **Methodology used to achieve objective “a.”**

Objective “a” consists of: Estimating the averages and levels of rainfall instability in the eight (8) climatic regions defined for Ceará. To achieve this objective, the averages and coefficients of variation (CV) of the rainfall observed in the municipalities that make up the eight climatic regions are estimated. By definition, the CV measures the percentage relationship between the standard deviation and the mean of a random variable. The CV is used as a measure of homogeneity/heterogeneity or stability/instability, which is the same thing, of the distribution of the observed values of a variable around its mean. The higher the CV, the more heterogeneous or unstable the distribution (Garcia, 1989; Nairy, Rao, 2003; Santos, Dias, 2021). According to Gomes (1985), CVs can be classified as low ( $CV < 10\%$ ); medium ( $10\% \leq CV < 20\%$ ); high ( $20\% \leq CV < 30\%$ ); and very high ( $CV \geq 30\%$ ).

#### **Indicators used to measure productive capacity**

Based on the definitions and rationale presented, and the justification provided for each of them, five (5) indicators were constructed to enable the assessment of the productive capacity of the municipalities. A comparative statistical study was conducted. The indicators tested are: 1 - Average annual rainfall in the municipalities ( $ANR_{jt}$ ) = average annual rainfall observed for municipality  $j$  ( $j = 1, 2, \dots, 168$ ) in year  $t$  ( $t = 1$  for 1996;  $t = 2$  for 2006 and  $t = 3$  for 2017). These sub-indices have the same interpretations as the other indicators. 2 - Biological ( $BIO_{jt}$ ) = sum of areas with woods, forests (native and planted) and areas with crops (perennial and temporary) in municipality “ $j$ ” for each year “ $t$ ”, divided by the total area of productive land in the municipality (in hectares). 3 - Animal Production Productivity ( $APP_{jt}$ ) = real value of aggregate livestock production, adjusted by the General Price Index (GPI) provided by the Getúlio Vargas Foundation (FGV) for the year 2020, divided by the total area used for pasture (in hectares) in municipality  $j$  in year  $t$ . 4 - Crop Productivity ( $VEG_{jt}$ ) = actual value of aggregate production of perennial and temporary crops, adjusted by the GPI for the year 2020, divided by the areas harvested with these crops (in hectares) in municipality “ $j$ ” and in year “ $t$ ”. 5 - Agricultural GDP in relation to the municipality's aggregate GDP ( $GDP_{jt}$ ) = agricultural GDP of the municipality / total GDP of municipality “ $j$ ” in year “ $t$ ”.

### **Construction of the agricultural production preservation index (IPPA)**

As noted, the indicators used in the study are measured in different units. To be aggregated, they need to be measured in a dimensionless manner. In this study, the strategy used to do so was to construct the agricultural production preservation index (IPPA) to aggregate the five indicators.

Indices are dimensionless measurement instruments that are constructed when one wishes to synthesize a larger amount of information or variables into a single number. In addition to aggregating variables measured in different units of measurement, these indices are useful for understanding a phenomenon, provided that one is aware of these construction problems. To be useful in assessing and understanding a problem, indices must have certain characteristics, such as simplicity, reproducibility, and ease of obtaining and measuring indicators (Briguglio, 2003).

Treating the indicators generically as  $Y_{ijt}$  ( $i = 1, 2, 3, 4, 5$ ;  $j = 1, 2, \dots, 168$ ;  $t = 1, 2, 3$ ), these indicators are transformed into partial indices ranging from zero (0) to one hundred (100), using the transformations shown in equation (1):

$$\hat{Y}_{ijt} = [(Y_{ijt} - Y_{mn}) / (Y_{mx} - Y_{mn})] \cdot 100 \quad (1)$$

In equation (1), the variable  $\hat{Y}_{ijt}$  measures the value observed for indicator “i” in the j-th municipality and in year “t”;  $Y_{mn}$  is the lowest value observed for the indicator in the three years under study;  $Y_{mx}$  is the highest value observed for the indicator in the three years studied. With this form of construction of the partial indices, it can be observed that they are relativized and vary between zero and one (1). The IPPA is defined in the form presented in equation (2):

$$IPPA_{ijt} = \sum w_{ijt} \cdot \hat{Y}_{ijt} \quad (2)$$

In equation (2), the variable  $\hat{Y}_{ijt}$  refers to the partial and relativized indicators, already defined, that make up the IPPA. The weights  $w_{ijt}$  are values greater than zero (0) and less than one (1) and, together, must add up to one (1) ( $0 < w_{ijt} < 1$ ;  $\sum w_{ijt} = 1$ ). To estimate these weights, we opted to use factor analysis (FA) through the principal component decomposition (PCD) technique. The following topic presents a summary of FA and PCD as they apply to this work.

Brief summary of the factor analysis procedure applied to the study

The technical foundations of FA lie in the correlation between the variables used. For the technique to be viable, the correlation matrix between the variables must not be an identity (Brooks, 2003; Thornton et al., 2008; Fávero et al., 2009; Guillaumont; Hahn et al., 2009; Lessa, 2023; Salviano et al., 2020; Simonet, 2011). Basically, factor analysis (FA) can be broken down into the following steps: a) analysis of the correlation matrix and suitability of the method; b) extraction of the initial factors and determination of the number of factors; c) rotation of factors, when more than one factor is extracted; and d) interpretation of factors, which includes the possibility of generating weights from the estimated factor scores (Fávero et al., 2009).

In order for FA to be performed properly, the following steps must be taken: analyze and test whether the correlation matrix between the indicators used in the study is not identical; check the Kaiser-Meyer-Olkin (KMO) statistic, whose minimum acceptable value is 0.5; evaluate the percentage of explanation of the accumulated variation of the estimated components. The variables are transformed into the standardized normal, which has a mean of zero and a variance of one.

The method used in this study to extract the factors was principal component analysis (PCA), which seeks a linear combination of the observed variables in order to maximize the total explained variance (Ather; Nimalathasan, 2009; Fávero et al., 2009).

### **Verification of differences in the means of the indicators and the IPPA in the evaluated years**

To assess whether there is a statistical difference between the means of the indicators and the IPPA estimated in 1996, 2006, and 2017, the following equation model is used:

$$Y_{it} = \beta_0 + \beta_1 D1 + \beta_2 D2 + \varepsilon_{it} \quad (3)$$

In equation (3), the indicator to be tested, as well as the estimated index, are generically represented by  $Y_{it}$ , where  $i$  is the number of municipalities ( $i = 1, 2, \dots, 168$ ) and  $t$  is the years studied ( $t = 1996; 2006$  and  $2017$ ).  $D1$  is a binary variable defined as follows:  $D1 = 1$  for values observed in 1996;  $D1 = 0$  for observations in 2006 and 2017. The binary variable  $D2$ , in turn, is defined as follows:  $D2 = 1$  for observations from 2006;  $D2 = 0$  for values observed in municipalities in 1996 and 2017. The linear coefficient  $\beta_0$  will measure the average of the indicator (or index) in 2017, when  $D1=D2=0$ . With regard to the angular coefficient  $\beta_1$ , if it is statistically different from zero, it implies that the average of the variable in 1996, in the 168 municipalities studied, is statistically different from the averages in the other two years. The angular coefficient  $\beta_2$ , being statistically different from zero, means that the average of the indicator in 2006 is different from the averages estimated for the years 1996 and 2017. The random term  $\varepsilon_{it}$ , by hypothesis, is white noise. Thus, the parameters  $\beta_0$ ,  $\beta_1$ , and  $\beta_2$  of equation (3) can be estimated using the ordinary least squares (OLS) technique (Wooldridge, 2010).

### Methodology for classifying municipalities according to IPPA magnitudes

Municipalities were classified according to their IPPA magnitudes, using the mean (MD) and standard deviation (SD) of the index over the three years evaluated as a reference. This decision was made so that the classifications adopted could be directly compared.

i - Municipalities with very high IPPA ( $IPPA^{MA}$ ) = those for which the index is higher than the mean plus one standard deviation: [ $IPPA^{MA} > (MD + SD)$ ]; ii - Municipalities with high IPPA ( $IPPA^{AL}$ ) = those in which the index is higher than the mean and lower than or equal to the mean plus one standard deviation: [ $MD < IPPA^{AL} \leq (MD + SD)$ ]; iii - Municipalities with medium IPPA ( $IPPA^{ME}$ ) = those in which the index is both less than or equal to its average value and greater than this value minus one standard deviation: [ $(MD - SD) < IPPA^{ME} \leq MD$ ]; iv - Municipalities with low IPPA ( $IPPA^{BX}$ ) = those in which the Index is less than or equal to the average value minus one standard deviation: [ $IPPA^{BX} \leq (MD - SD)$ ].

## IV. Result And Discussion

The results found to assess objective “a” of the research are shown in Table 1. The results found in Table 1 show that the highest average rainfall occurred in 1996 in all climatic regions and the lowest occurred in 2017, as expected, given that 2017 was the last year in the long period of rainfall drought that began in 2012. It can also be observed that in 2017, rainfall in general showed the lowest instability among the regions. Instabilities ranged from 18.94% (average) in the Baturité Massif in 2017 to 30.59% (very high) in the Ibiapaba region in 2006 (Table 2).

Table no 2: Averages and Coefficients of Variation of rainfall in the climatic regions of Ceará in 1996, 2006, and 2017

| Climate Regions                 | Rainfall in 1996 (mm) |       | Rainfall in 2006 (mm) |       | Rainfall in 2017 (mm) |       |
|---------------------------------|-----------------------|-------|-----------------------|-------|-----------------------|-------|
|                                 | Average               | CV    | Average               | CV    | Average               | CV    |
| Cariri                          | 1021,88               | 21,41 | 891,47                | 23,7  | 765,6                 | 19,6  |
| Ibiapaba                        | 1132,99               | 28,33 | 945,17                | 30,59 | 798,82                | 19,45 |
| Jaguaribana                     | 1146,5                | 26,48 | 1011,88               | 24,22 | 843,55                | 17,27 |
| Fortaleza Coastal               | 1038,73               | 19,62 | 941,1                 | 17,45 | 817,26                | 15,34 |
| Pecém Coastal                   | 1088,05               | 27,05 | 969,11                | 24,67 | 814,05                | 20,47 |
| North Coastal                   | 1084,5                | 25,94 | 919,33                | 26,96 | 807,44                | 19,02 |
| Baturité Massif                 | 1014,75               | 21,94 | 906,35                | 26,80 | 773,68                | 18,94 |
| Central Hinterland and Inhamuns | 1049,13               | 28,30 | 908,75                | 27,46 | 772,91                | 20,42 |

Source: Xavier, 2020 and Funceme, 2020.

The results of the factor analysis to estimate the weights used to construct the production capacity prevention index (IPPA) for the agricultural sector of the 168 municipalities in the semi-arid region of Ceará studied are presented in Table 3. It can be seen that the five variables were summarized into a single componente. Table no 3: Results of the decomposition into principal components to estimate the weights used in the IPPA in the municipalities of Ceará in 1996, 2006, and 2017.

| Indicators              | Components | Factorial scores | Weights |
|-------------------------|------------|------------------|---------|
| CHU                     | 0,618      | 0,367            | 0,22    |
| BIO                     | 0,790      | 0,469            | 0,28    |
| PEC                     | 0,575      | 0,341            | 0,20    |
| VEG                     | 0,452      | 0,268            | 0,16    |
| PBR                     | 0,381      | 0,226            | 0,14    |
| KMO                     | 0,753      |                  |         |
| Xi square               | 174,751    |                  |         |
| Degrees of Freedom (GL) | 10         |                  |         |
| Significance            | 0,000      |                  |         |
| Explained Variance (%)  | 50,842     |                  |         |

Sources: Values estimated based on original data from IBGE for 1995/96, 1999, 2006, 2017, and from Funceme, 2020.

It should be noted that the results found are statistically robust, given that all statistics relevant to the model adequacy tests used proved to be significant. The magnitude of the KMO test was greater than the minimum

acceptable value of 0.5. The chi-square statistic used to perform the Bartlett test shows that the hypothesis that the correlation matrix is identity is rejected. The weights generated from the components, or estimated factor scores, show that the indicators that contribute the most weightings are, respectively, vegetation cover (BIO) and rainfall (CHU).

The next step was to assess whether the indicators used to estimate the IPPA in the three years, as well as this index, differ statistically in 1996, 2006, and 2017. To perform this test, the model with binary variables presented in Equation (3) in the Methodology section is used. These results are shown in Table 4.

It can be observed that rainfall (CHU), on average, was statistically higher in 1996 than in the other two years. The same was true for the vegetation cover indicator (BIO) and the relative share of agricultural GDP in total GDP (PBR) and IPPA. With regard to livestock productivity (PEC), this was the only indicator for which the average was higher in 2017 than in the other years. The crop productivity indicator (VEG), in turn, was higher in 2006 (Tables 4 and 5).

Table no 4: Results obtained from tests to assess whether the indicators used and the IPPA are statistically different in 1996, 2006, and 2017.

| Indicators | Adjusted R <sup>2</sup> | Constant  |       | D1        |       | D2        |       |
|------------|-------------------------|-----------|-------|-----------|-------|-----------|-------|
|            |                         | Estimated | Sign. | Estimated | Sign. | Estimated | Sign. |
| CHU        | 0,079                   | 737       | 0     | 276,62    | 0     | 73,58     | 0,003 |
| BIO        | 0,33                    | 0,396     | 0     | 0,281     | 0     | 0,257     | 0     |
| PEC        | 0,018                   | 1057,109  | 0     | -42,915   | 0,722 | -39,253   | 0,745 |
| VEG        | 0,066                   | 1218,855  | 0     | 503,324   | 0,001 | 896,927   | 0     |
| PBR        | 0,112                   | 0,146     | 0     | 0,073     | 0     | 0,053     | 0     |
| IPPA       | 0,283                   | 30,656    | 0     | 14,577    | 0     | 12,266    | 0     |

Sources: Values estimated based on original data from IBGE for 1995/96, 1999, 2006, and 2017, and from Funceme, 2020.

Thus, in general, it can be seen that rainfall influenced the definitions of all indicators used to construct the IPPA. These behaviors are summarized in Table 4, which shows the averages for each of these IPPA indicators, as well as their hierarchies represented by the super-indices A, B, and C, where A > B > C.

Table no 5: Averages for rainfall (CHU), vegetation cover (BIO), livestock production value per hectare of pasture (PEC), crop production value (perennial and temporary crops) per hectare (VEG), and the ratio between agricultural GDP, total municipal GDP, and IPPA in 1996, 1999, 2006, and 2017.

| Indicators | Years                |                      |                      |
|------------|----------------------|----------------------|----------------------|
|            | 1996                 | 2006                 | 2017                 |
| ARN        | 1013,62 <sup>A</sup> | 810,58 <sup>B</sup>  | 737,00 <sup>C</sup>  |
| BIO        | 0,68 <sup>A</sup>    | 0,65 <sup>B</sup>    | 0,40 <sup>C</sup>    |
| APP        | 1014,19 <sup>B</sup> | 1017,86 <sup>B</sup> | 1057,11 <sup>A</sup> |
| VEG        | 1722,18 <sup>B</sup> | 2115,78 <sup>A</sup> | 1218,86 <sup>C</sup> |
| GDP        | 0,22 <sup>A</sup>    | 0,20 <sup>B</sup>    | 0,15 <sup>C</sup>    |
| IPPA       | 45,23 <sup>A</sup>   | 42,92 <sup>B</sup>   | 30,66 <sup>C</sup>   |

Sources: Values estimated from original data from IBGE for 1995/96, 1999, 2006, and 2017, and from Funceme, 2020. Notes: The superscripts A, B, and C mean that the averages can be ranked as follows: A > B > C.

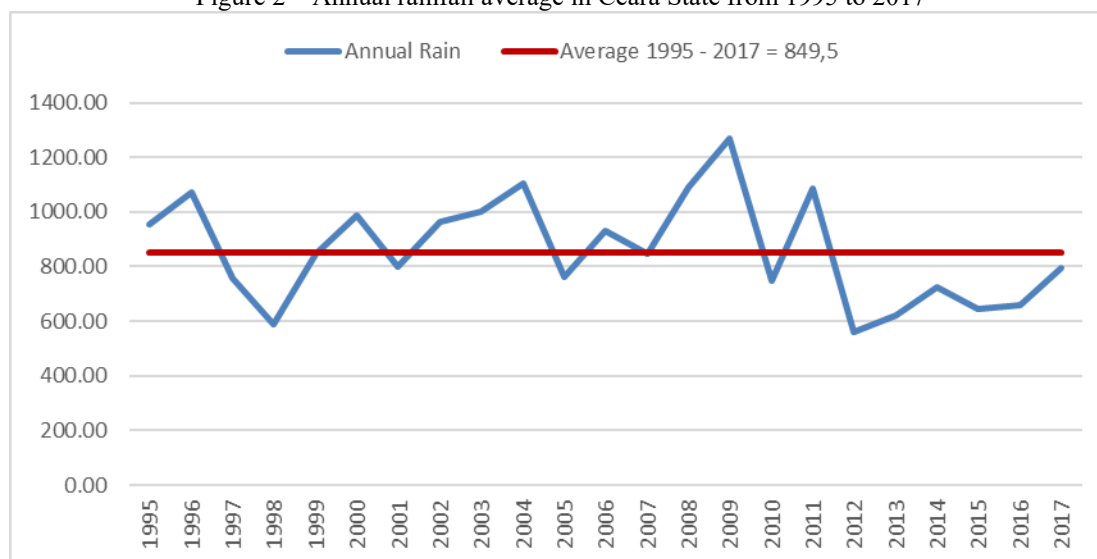
These results are also reflected in the hierarchy of the estimated IPPA averages for the three years. The average IPPA for 1996 is 2.31% higher than that observed in 2006 and 14.57% higher than that observed for 2017. This is a significant difference in the reduction in the productive capacity of the semi-arid region of Ceará in the two periods (2006 and 2017) compared to the base year (1996). It is worth remembering that between 2012 and 2017 there were years of drought in most of the municipalities of Ceará. These events were reflected in the agricultural production of almost all municipalities in the state during that period.

Figure 2 illustrates the rainfall in Ceará between 1995 and 2017, as well as the estimated average for the period, which was 839.6 mm. It can be seen that in 1995, the year preceding the collection of information for the 1996 Agricultural Census, the average rainfall in Ceará was 1067.10 mm, and in 1996, it rained an average of 1064.10 mm. In 2006, it rained 830.10 mm in Ceará. According to Funceme (2020), 2017 ended a period of drought in Ceará, which recorded 551.20 mm in 2014; in 2015, it rained 532.70 mm; in 2016, the rainfall recorded in the state was 554.60 mm, culminating in rainfall of only 698.20 mm in 2017.

Thus, the results associated with virtually all indicators used to measure Ceará's productive capacity, as well as the IPPA in 2017, can be attributed to this sequence of rainfall difficulties that preceded 2017 and

influenced the year itself. It should also be noted that the average rainfall measured between 1996 and 2017 was 849.5 mm. The rainfall for 1995 was included in the calculation because it must also have contributed, through the formation of expectations, to the more favorable results in 1996. It can be seen that the rainfall level in 1996 was the most abundant compared to the other two years studied in the research.

Figure 2 – Annual rainfall average in Ceará State from 1995 to 2017



Source: Funceme, 2020.

Table 6 shows the amounts for municipalities classified according to the magnitudes of their respective IPPA, using the averages observed for the index in 1996, 2006, and 2017 as a reference. Because the scales were constructed based on these values in the three years of evaluation, the classifications presented can be compared with each other. Thus, the evidence shown in Table 5 suggests that the situation is quite unfavorable for the municipalities studied in 2017 in relation to other years, especially when compared to 1996.

Table no 6: Number of municipalities according to the classification of production capacity levels measured in the study in 1996, 2006, and 2017.

|              | Year 1996      |              | Year 2006      |              | Year 2017      |              |
|--------------|----------------|--------------|----------------|--------------|----------------|--------------|
|              | Municipalities | Average      | Municipalities | Average      | Municipalities | Average      |
| Very High    | 39             | 56,68        | 32             | 58,63        | 8              | 55,72        |
| High         | 86             | 44,84        | 67             | 44,65        | 35             | 45,7         |
| Medium       | 41             | 36,1         | 65             | 34,57        | 44             | 32,97        |
| Low          | 2              | 26,26        | 4              | 23,93        | 81             | 20,43        |
| <b>Total</b> | <b>168</b>     | <b>45,23</b> | <b>168</b>     | <b>42,92</b> | <b>168</b>     | <b>30,66</b> |

Sources: Values estimated based on original data from IBGE for 1995/96, 2006, and 2017, and from Funceme, 2020.

For example, in 2017, 81 (48.2%) municipalities were classified as having low IPPA, compared to 4 municipalities in 2006 and only 2 in 1996. On the other hand, 39 (23.21%) and 32 (19.1%) municipalities, respectively, in 1996 and 2006 had their IPPA classified as Very High. In 2017, only 8 (4.8%) municipalities had their estimated IPPA considered in this category. In contrast, 86 (51.2%) municipalities in 1996 had IPPA considered high. In 2006, there were 67 (40.0%), and in 2017, only 35 (20.8%) could be classified in this category (Table 6).

## V. Conclusion

The study aimed to answer the following question: Is there synergy between rainfall and indicators of vegetation cover, land cover, and income generation in rural areas of municipalities in Ceará officially recognized as part of the Brazilian semi-arid region?

The question was answered in full, given that the study created the agricultural production preservation index (IPPA), which incorporates five indicators in a weighted manner: annual rainfall in the municipalities; vegetation cover; land productivity in crop production; land productivity in animal production; and the relative share of the municipalities' agricultural GDP in relation to the municipalities' aggregate GDP in 1996, 1999, 2006, and 2017. The indicators were constructed in a relative manner. To this end, they were transformed into indices using the maximum-minimum technique.

The results showed that in the interaction of these five indicators, the year 1996, which was taken as the reference year, presented the best results in terms of preserving productive capacity. And in that year, average rainfall was higher than that observed in 2006 and 2017.

In contrast, 2017, which marked the end of a long period of drought in Ceará that had begun in 2012, was the year that showed the lowest level of preservation of productive capacity in the agricultural sector of the state's semi-arid municipalities. The difference in rainfall observed in the three years studied must have contributed to the differences between the indicators observed, in general, in the three years. Only livestock productivity, which measured the relationship between the value of livestock production and the area occupied by this activity in the municipalities of the semi-arid region of Ceará, showed a higher average in 2017 than in the other years investigated.

The evidence of the relevance of rainfall in the rural production capacity of the semi-arid region is confirmed in the study when presenting the list of the twenty (20) municipalities best positioned in relation to the agricultural production preservation index (IPPA), which are located in the mountainous and coastal areas where rainfall is more abundant. This can be observed in the three years investigated.

On the other hand, the municipalities that showed the lowest agricultural production preservation capacities are located in the areas with the greatest rainfall difficulties in the state of Ceará, mainly Sertão Central and Inhamuns.

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