Journal of Agricultural Science and Technology A 12 (2022) 1-9
doi: 10.17265/2161-6256/2022.01.001

Relationship between Rainfall Instability and Agricultural Production in the Brazilian Semi-arid Region

José de Jesus Sousa Lemos, Natália de Oliveira Gurjão and Maria Beatriz Cunha Pinheiro

Federal University of Ceará, Fortaleza, CE 60455-760, Brazil

Abstract: The study evaluated the synergy between the indicators of rainfall, vegetation cover, land productivity in crop production, livestock production and the relationship between the value of aggregate agricultural production and the gross domestic product of municipalities in the semi-arid region of the State of Ceará, Brazil. The data sources are: Ceará Meteorology and Water Resources Foundation (FUNCEME) and Brazilian Institute of Geography and Statistics (IBGE) for the years 1996, 2006 and 2017. The research used the methodology of factor analysis (FA), with decomposition into principal components, to construct the index of agricultural production preservation (IAPP). The results showed that 1996 had the best rainfall levels and the highest IAPP values compared to the other years studied. Year of 2017 was the last one of a draught period that extended in Ceará from 2012 to 2017. In that year the lowest values for IAPP were observed. The main conclusion is: there was the expected interaction between rainfall and agricultural preservation indicators applied in the semi-arid region of the state of Ceará in the years 1996, 2006 and 2017.

Key words: Degradation, natural resources, desertification, rainfed agriculture, Brazilian semi-arid region.

1. Introduction

The agricultural production in the Northeast region of Brazil experiences great obstacles associated with a complex synergy of factors that contribute to the depredation of the natural resource base of the region and make it difficult, or even impossible, to produce agricultural goods in a good part of the municipalities of the nine States that compose it.

In Ceará State of Brazil, the situation is not very different, considering that the levels of land productivity and production value per hectare achieved by agricultural and pastoral activities are very low. This, possibly, is due to the vulnerabilities imposed by the instability of rainfall and the still low technological standard in which, in general, agricultural and livestock activities are practiced in the state, being not adapted to these climatic difficulties [1, 2].

In the Brazilian semi-arid region, the intermittency of rainfall is observed, both in space and time. Between 2010 and 2017, with a truce in 2011, Ceará State, as well as the entire semi-arid region, experienced a long period of drought that had important repercussions on plant production, animal husbandry, floristic covering, fauna diversification, the replenishment of underground aquifers (water table, mainly) and surface aquifers, including the dams built for water storage. Ceará State currently has 171 of its 184 municipalities officially recognized, by Brazilian Government, as being part of the semi-arid climate [3].

In addition, temperatures in the State are high and air humidity is low [4]. The soils are shallows and, in general, have low natural fertility. In addition, in considerable parts of the state's surface there is crystalline outcropping. The vegetation cover, characteristic of the semi-arid region of Ceará State, such as the one that prevails mostly in this climatic regime in Brazil, is the *caatinga* (scrub vegetation).

This coverage is very degraded by the human activities that come from predatory agriculture practiced

Corresponding author: José de Jesus Sousa Lemos, Ph.D., professor, research field: agricultural economics.

both, by family farmers and by non-family farms units. Another factor that contributes to the degradation of the state and regional *caatinga* is the removal of the cover to serve as firewood or charcoal, which is used for cooking food in rural homes, mostly very poor, or to burn in furnaces in bakeries, potteries, usually located far from the areas of removal [5, 6].

This synergy between human and natural agents makes the semi-arid regions present levels of productive preservation capacity in difficult situations, also as a result of the heterogeneity of the geographic diversity of the State, which presents environments of coasts, hinterlands and mountains. Each of these regions has specific climate conditions, translated into temperatures, humidity and rainfall level [7-9].

Ceará State, like in Brazilian semi-arid region, prevails rainfed agriculture. This kind of agriculture, for most small family farmers, depends on the availability of natural resources, principally rainfall regularity. As it is impossible to exercise any control over nature, the oscillations of rainfed crops are due to the variability of weather conditions, over which farmers have no defense mechanisms. These are, therefore, high risk activities. The fragilities of this production system are reflected in the oscillations of harvested areas, yields, productivity, prices, and income associated with these activities [2, 5, 10-14].

In view of the above, the principal assumption of this job is: because of the prevailing rainfed agriculture in semi-arid region, there are strong relationships between rainfall and indicators of agricultural production preservation in this area.

Because of this assumption this research has the following objectives: (a) to evaluate, in a comparative way, the indicators of vegetation cover, land productivity and relative participation of the rural sector gross domestic product (GDP) over the aggregate GDP of the Ceará State semi-arid municipalities in the years 1996, 2006 and 2017; (b) to evaluate the differences of agricultural production preservation of municipalities between the years of 1996, 1999, 2006 and 2017; (c) to develop ranges for defining the agricultural production prevention of these municipalities in each of these years.

2. Methodology

This research is anchored in the concept of preservation of the agricultural production preservation in face of climate variations in the semi-arid regions. The preservation of agricultural production is understood as the capacity of the soil to raise, or at least maintain, the aggregate production in a sequence of years, taking into consideration the climatic variations, especially the rainfall instabilities that are the rule in semi-arid regions, where rainfed agriculture prevails [15-17].

For the selection of indicators, construction of the instrument is used to evaluate how the vegetation cover, animal, and agricultural productivities evolved in the municipalities of Ceará State in three periods based on the last Agricultural Censuses of 1995/96, 2006, and 2017.

The observation units are the municipalities of Ceará State included in the semi-arid region according to the latest report of the Ministry of National Integration [3]. The data used in the research were collected from the 2020 publication of the Meteorology and Water Resources Foundation of Ceará State [4] and the 1996, 2006 and 2017 Agricultural Censuses of the Brazilian Institute of Geography and Statistics (IBGE) for the State of Ceará. The search also used the aggregated GDP of the municipalities in the years 1999, 2006, and 2017 made available by IBGE. This is because the IBGE began to disclose the municipalities GDP only in 1999. These values are used as proxies for GDP of 1996. Ceará State has 184 municipalities since 1996. However, only 171 municipalities are officially recognized as semi-arid [3].

2.1 Indicators Used to Measure Productive Capacity

There were five (5) indicators used to make possible to gauge the agricultural production preservation of municipalities. In selecting the indicators, the research was based on the study made by Lemos *et al.* [5] who mapped desertification in Northeastern municipalities and Choudhary *et al.* [7] who assessed some of the main causes of environmental degradation. These indicators are:

(a) Annual rainfall (CHU_{it}) = observed annual rainfall for municipality i (i = 1, 2, ..., 175) in year t (t = 1 for 1996, t = 2 for 2006, and t = 3 for 2017).

(b) Biological indicator (BIO_{it}) = the sum of areas with forests (native and planted) and areas with crops (both perennial and temporary) of the municipality "*i*" for each year "*t*", divided by the total area of productive lands of the municipality (in hectares).

(c) Animal Productivity (PEC_{it}) = real value of aggregate livestock production, corrected by the General Price Index (IGP-DI) made available by the Getúlio Vargas Foundation (FGV), for the year 2018, divided by the total areas allocated to pastures (in hectares) of municipality i in year t.

(d) Crop Productivity (VEG_{it}) = real value of the aggregate production of perennial and temporary crops, corrected by the IGP-DI, for the year 2018, divided by the areas harvested with these crops (in hectares) in municipality "*i*" and in year "*t*".

(e) Agricultural GDP in relation to the aggregated GDP of the municipality (PBR_{it}) = agricultural GDP of the municipality/total GDP of the municipality "*i*" in year "*t*".

2.2 Index of Agricultural Production Preservation (IAPP)

As is noted, the indicators used in the research are measured in different units. To be aggregated they need to be measured in dimensionless units. In this research the strategy used to do this was to construct the IAPP to aggregate the five indicators duly transformed.

Indexes are dimensionless measuring instruments that are built when a larger amount of information is to be synthesized in a single number. For the indexes to be useful in the evaluation and understanding of an economic problem, they must have some characteristics such as: simplicity, ability to be reproduced, and ease in obtaining and measuring their indicators [18].

To build the IAPP, factor analysis (FA) was used through the principal component decomposition (PCD) technique. The following topic presents a synthesis of the FA and PCD as it is applied to the work.

2.3 Brief Summary of the FA Procedure That Is Applied to This Study

The technical underpinnings of FA lie in the correlation between the variables that are used. For the technique to be viable, it is necessary that the correlation matrix between the variables is not an identity [3, 19-23].

In order to apply the AF in the appropriate way it is necessary to perform the following steps: analyze and test if the correlation matrix between the indicators used in the study is not an identity; verify 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 method used in this study to extract the factors was the principal component decomposition (PCD) [22, 24].

In the case of this study the five variables are reduced into a single factor and a single factorial score (F_{it}), which has zero mean and unit variance. This means the fluctuation of positive and negative values around the mean [3, 22, 23].

The IAPP was constructed to vary between zero and one hundred ($0 \leq IAPP \leq 100$). Municipalities with IAPP closed to 100 are indicators of high agricultural production preservation. On the other hand, values of IAPP tending to zero, indicate low agricultural production preservation of the municipality. In order to make IAPP range in between this value the transformation is used shown in Eq. (1):

$$IAPP_{it} = [(F_{it} - F_{mn}) / (F_{mx} - F_{mn})] \times 100 \quad (1)$$

In Eq. (1), F_{mn} is the minimum value of F_{it} and F_{mx} is its maximum value.

2.4 Differences in the IAPP and the Means of the Indicators in the Evaluated Years

To evaluate whether there is a statistical difference between the averages of the indicators and the IAPP estimated in 1996, 2006 and 2017 the following equation model is used:

$$X_{it} = \beta_0 + \beta_1 D1 + \beta_2 D2 + \varepsilon_{it} \quad (2)$$

In Eq. (2) the indicators to be tested, as well as the estimated index, are represented generically by X_{it}, where "i" is the number of municipalities (i = 1, 2, ..., 168) and "t" is the years studied (t = 1996, 2006 and 2017). D1 is binary variable that is defined as follows: D1 = 1 for the values observed in 1996; D1 = 0 for the observations in 2006 and 2017. The binary variable D2, in turn, is defined as follows: D2 = 1 for the 2006 observations; D2 = 0 for the values observed in the municipalities in 1996 and 2017. The linear coefficient β_0 will gauge the average of the indicator (or index) in the year 2017, when D1 = D2 = 0. With regard to the angular coefficient β_1, if it is statistically different from zero, it implies that the average of the variable in 1996 is statistically different from the averages of those occurring in the other two years. The angular coefficient β_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 ε_{it}, by hypothesis, is white noise. Therefore, the parameters β_0, β_1 and β_2 of Eq. (2) can be estimated using the ordinary least squares (OLS) technique [25].

2.5 Methodology to Classify the Municipalities according to the Magnitudes of the IAPP

The municipalities were classified according to the magnitudes of the IAPP, taking as reference the mean (MD) and the standard deviation (SD) of the index in the three evaluated years. This decision was made so that the adopted classifications can be directly compared.

(i) Municipalities with very high IAPP ($IAPP_{VH}$): $IAPP_{VH}$ > (MD + SD);

(ii) Municipalities with high ($IAPP_{HI}$): MD < $IAPP_{HI} \leq$ (MD + DP);

(iii) Municipalities with average IAPP ($IAPP_{AV}$): (MD - DP) < $IAPP_{AV} \leq$ MD;

(iv) Municipalities with low IAPP ($IAPP_{LO}$): $IAPP_{LO} \leq$ (MD- DP).

To make up all the estimations used in this paper, this paper used the 20.0 version of the Statistical Package for the Social Sciences (SPSS).

3. Results and Discussion

The estimated results of the FA used in this study to estimate IAPP are presented in Table 1. As can be seen in this table the five indicators were reduced to one factor.

Table 1 Results of decomposition into main components to estimate the weights used in the IAPP in the municipalities of Ceará in 1996, 2006 and 2017.

Indicators	Components	Factor scores coefficients
CHU	0.618	0.367
BIO	0.790	0.469
PEC	0.575	0.341
VEG	0.452	0.268
PBR	0.381	0.226
KMO	0.553	
Chi square	174.751	
Degrees of freedom (DF)	10	
Sign	0.000	
Explained variance (%)	50.842	

Sources: IBGE (1995/96, 1999, 2006 and 2017) and FUNCEME [4].

Table 2 Results obtained with the tests to assess whether the indicators used and the IAPP are statistically different in 1996, 2006 and 2017.

Indicators	Adjusted R^2	Constant		D1		D2	
		Estimated	Sign.	Estimated	Sign.	Estimated	Sign.
CHU	0.079	737.000	0.000	276.620	0.000	73.580	0.003
BIO	0.330	0.396	0.000	0.281	0.000	0.257	0.000
PEC	0.018	1,057.109	0000	-42.915	0.722	-39.253	0.745
VEG	0.066	1,218.855	0.000	503.324	0.001	896.927	0.000
PBR	0.112	0.146	0.000	0.073	0.000	0.053	0.000
IAPP	0.283	30.656	0.000	14.577	0.000	12.266	0.000

Sources: IBGE (1995/96, 1999, 2006 and 2017) and FUNCEME [4].

It is observed that the results are robust from a statistical point of view, because all the relevant statistics to elaborate the tests adequacy of FA, proved to be significant. The magnitude of the KMO test (0.553) was greater than the minimum acceptable value, which is 0.5. For AF to be suitable, it is necessary that the correlations between the used variables are not linearly independent. This implies that the correlation matrix between them is not an identity. To evaluate this hypothesis the Bartlet test is used. In this study the Bartlett's test, which is summarized in the chi-square statistic, shows the rejection of the hypothesis that the correlation matrix is an identity. The explained variance is 50.842% (Table 1).

The next step was to evaluate whether the indicators used to estimate the IAPP, in the three years, as well as whether this index differs statistically in 1996, 2006 and 2017. To perform this test, this paper used the model with binary variables presented in Eq. (2) in the Methodology Section. These results are shown in Tables 2 and 3.

It is observed that rainfall (CHU), on average, was statistically higher in 1996 than in the other two years (2006 and 2017). The same happened with vegetation cover indicator (BIO) and with the relative participation of agricultural GDP over the total GDP and IAPP. With regard to livestock productivity (PEC), this was the only indicator in which the average was higher in 2017 than in the other years. The indicator of plant productivity (VEG), in turn, was higher in 2006.

Thus, in general, it can be seen that rainfall influenced the definitions of all indicators used to construct the IAPP. These behaviors are summarized in Table 3 where the averages of each of these IAPP indicators are shown, as well as their hierarchies represented by the super-indices, A, B and C where A > B > C.

Table 3 Averages of rainfall indicators (CHU), vegetation cover (BIO), value of livestock production per hectare of pasture (PEC), value of vegetable production (perennial and temporary crops) per hectare (VEG) and ratio between agricultural GDP and total GDP of municipalities in 1996, 2006 and 2017.

Indicators	Years		
	1996	2006	2017
CHU	$1,013.62^a$	810.58^b	737.00^c
BIO	0.68^a	0.65^b	0.40^c
PEC	$1,014.19^b$	$1,017.86^b$	$1,057.11^a$
VEG	$1,722.18^b$	$2,115.78^a$	$1,218.86^c$
PBR	0.22^a	0.20^b	0.15^c
IAPP	45.23^a	42.92^b	30.66^c

Sources: IBGE (1995/96, 1999, 2006 and 2017) and FUNCEME [4]. Values with up indices "a" are statistically greater than those with up indices "b" and "c". Values with up indices "b" are statistically greater than those with up indices "c".

An expressive difference was observed in the reduction of agricultural production preservation of the Ceará State semi-arid region in the two periods (2006 and 2017) compared to the base year (1996). It is worth remembering that between 2010 and 2017 there were years of drought in most of the municipalities of Ceará State. These events were reflected in the agricultural production of almost all municipalities in the state in that period.

Fig. 1 illustrates the rainfall in Ceará State between the years 1995 and 2017, as well as the estimated average for the period, which was 729.8 mm. It can be seen that in 1995, the year before the collection of information for the 1996 Agricultural Census, the average rainfall in Ceará State was 1,067.10 mm, and in 1996 it rained, on average, 947.1 mm. In 2006 it rained 956.50 mm. The year 2017, according to FUNCEME [4], ended a circuit of dry spells in Ceará State that, in 2014, recorded 546.1 mm; in 2015 it rained 523.1 mm; in 2016 the precipitation recorded in the state was 554.6 mm, culminating with precipitation of only 698.20 mm in 2017. Thus, it can be debited in this sequence of rainfall difficulties, which preceded the year 2017 and influenced in the year itself, the results associated with practically all the indicators used in gauging the productive capacity of Ceará State, as well as in the IAPP in 2017 (Fig. 1) .

These results are also reflected in the hierarchy of the average estimated IAPP for the three years: $IAPP_{1996}$ > $IAPP_{2006}$ > $IAPP_{2017}$. This was the same hierarchy for the rainfall: CHU_{1996} > CHU_{2006} > CHU_{2017} (Table 3, Fig. 1).

The good rainfall that occurred in 1995 must have influenced farmers' decisions for the 1996 production that ended up benefiting from the good rainfall levels of that year. This set of good events, from a rainfall point of view, may have influenced the better performance for IAPP observed in 1996 relative to what happened in 2006 and 2017 [4].

Table 4 presents the amounts of municipalities according to their classifications based on the values of their respective IAPP, with the averages observed for the aggregated indexes in the years 1996, 2006, and 2017 as references.

From the evidence shown in Table 4, it can be inferred that the situation is quite unfavorable for the municipalities studied in 2017 in relation to the other years, especially in relation to the base year of 1996.

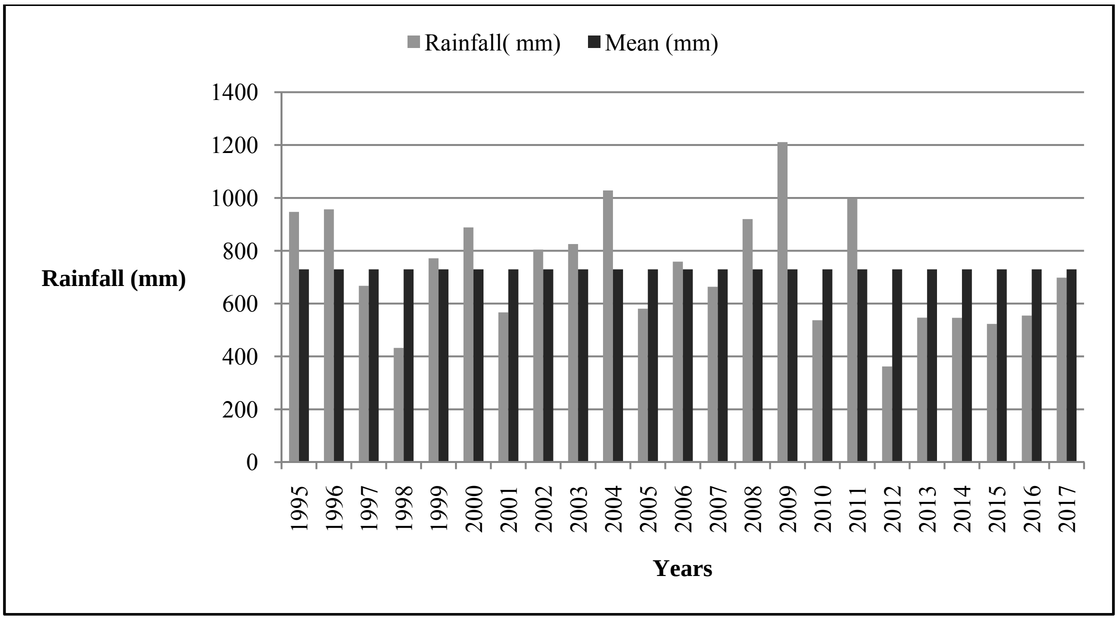

Fig. 1 Yearly rainfall in Ceará State from 1995 to 2017.
Source: FUNCEME [4].

Table 4 Number of municipalities according to the qualification of production capacity levels measured in 1996, 2006 and 2017.

	Year 1996		Year 2006		Year 2017	
	Munic.	Mean	Munic.	Mean	Munic.	Mean
Very high	39	56.68	32	58.63	8	55.72
High	86	44.84	67	44.65	35	45.70
Median	41	36.10	65	34.57	44	32.97
Low	2	26.26	4	23.93	81	20.43
Total	168	45.23	168	42.92	168	30.66

Sources: Estimated values from original IBGE Data: 1995/96, 2006 and 2017 and from FUNCEME [4].

It can be seen, for example, that in 2017, a total of 81 (48.2%) municipalities were observed with IAPP considered as Low, compared to 4 municipalities in 2006, and only 2 in 1996 in such situations. On the other hand, there were 39 (23.21%) and 32 (19.1%) municipalities, respectively, in 1996 and 2006 that had their IAPP classified as Very High. In 2017, only 8 (4.8%) municipalities had their estimated IAPP considered in this category. In contrast, there were 86 (51.2%) municipalities in 1996 that had IAPP considered as High. In 2006 there were 67 (40.0%) and in 2017, only 35 (20.8%) could be classified in this category (Table 4).

4. Conclusions

The study aimed to answer the following question: how does the synergy between rainfall and indicators of vegetation cover, land productivity and income generation manifest itself in the rural sector of the semiarid municipalities of the state of Ceará?

The questioning was answered in full, given that the IAPP was created in the study that incorporates five indicators related to: annual rainfall of the municipalities; vegetal cover; land productivity in vegetal and animal production and aggregated GDP of Ceará States municipalities in years 1996, 2006 and 2017.

The results showed the principal assumption of this study: the synergy between rainfall and agricultural production preservation in semi-arid region of Ceara State. This is because in 1996 the highest rainfall level was observed in this State. In that year the greatest agricultural production preservation was observed. In contrast, in 2017, which culminated a long period of drought in Ceará State, started in 2010 with a truce in 2011, was the year that showed the lowest aggregate capacity to preserve the production preservation in the agricultural sector of the municipalities situated in the semi-arid region of this State. This differential in rainfall observed in the three observed years must have contributed to the differences between the indicators that were observed, in general, in the three studied years.

The general conclusion of the research is that the interaction between rainfall and the aggregate animal and vegetable production in the municipalities of Ceará States defines the good or bad results observed for these productions preservations in the years studied. Thus, the study confirms, in a quantified way, that it is necessary to create production alternatives for coexistence with agricultural production (vegetable and animal) considering the only certainty that has in the semi-arid region: the temporal and spatial instability of rainfall.

References

[1] Ceará. 2010. *State Action Program to Combat Desertification and Mitigate the Effects of Drought, PAE-CE*. Fortaleza, CE: Secretary of Water Resources, 372. http://www.mpce.mp.br/wpcontent/uploads/2016/05/PROGRAMA-ESTADUAL-DE-COMBATE-A-DESERTIFICA%C3%87%C3%83O.pdf. (in Portuguese)

[2] Salviano, J. I. A. 2021. "Relations between Rainfall Instabilities and Production Indicators of Rainfed Crops in the Semi-arid Region of Ceará." M.Sc. thesis, Federal University of Ceará.

[3] http://repositorio.ufc.br/bitstream/riufc/59607/1/2021_dis_jiasalviano.pdf. (in Portuguese)
[4] Brazil: Superintendence for the Development of the Northeast (SUDENE) 2017. Delimitation of the Semi-arid Region. http://www.sudene.gov.br/delimitacao-do-semiarido. (in Portuguese)
[5] FUNCEME. 2020. *Ceara Foundation of Meteorology and Hydric Resources. Rainfall calendar for the State of Ceará.* Fortaleza, Ceará.
[6] http://www.funceme.br/app/calendario/produto/municipios/maxima/anual. (in Portuguese)
[7] Lemos, J. J. S. 1995. "Desertification in Drylands in Northeast of Brazil. Riverside, CA." Working Paper, Department of Economics, University of California.
[8] Singh, R., and Singh, G. S. 2017. "Traditional Agriculture: A Climate-Smart Approach for Sustainable Food Production." *Energy, Ecology and Environment* 2 (5): 296-316. https://link.springer.com/article/10.1007/s40974-017-0074-7.
[9] Choudhary, M. P., Chauhan, G. S., and Kushwah, Y. K. 2015. "Environmental Degradation: Causes, Impacts and Mitigation." In *Proceedings of the National Seminar on Recent Advancements in Protection of Environment and Its Management Issues (NSRAPEM-2015).* https://www.researchgate.net/publication/279201881_Environmental_Degradation_Causes_Impacts_and_Mitigation.
[10] Lal, R. 2015. "Restoring Soil Quality to Mitigate Soil Degradation." *Sustainability* 7 (5): 5875-95. https://www.mdpi.com/2071-1050/7/5/5875.
[11] Lemos, J. J. S., and Bezerra, F. N. R. 2019. "Interference of Pluviometric Instability in the Forecast of Grain Production in the Semiárido of Ceará, Brazil." *Braz. J. of Develop. Curitiba* 5 (9): 15632-52. https://www.brazilianjournals.com/index.php/BRJD/article/view/3294/3157.
[12] Duque, J. G. 2001. *Soil and Water in the Polygon of Droughts* (6th ed.). Mossoró: Esam, Coleção Mossoroense. (in Portuguese)
[13] Fischer, G., Shah, M., and van Velthuizen, H. 2002. *Climate Change and Agricultural Vulnerability*. Johannesburg: International Institute for Applied Systems Analysis to World Summit on Sustainable Development.
[14] Wani, S. P., Sreedevi, T. K., Rockström, J., and Ramakrishna, Y. S. 2008. "Rainfed Agriculture: Past Trends and Future Perspectives." In *Rainfed Agriculture: Unlocking the Potential*, 1-35. http://www.iwmi.cgiar.org/Publications/CABI_Publications/CA_CABI_Series/Rainfed_Agriculture/Protected/Rainfed_Agriculture_Unlocking_the_Potential.pdf.
[15] Brasil Centro de Gestão e Estudos Estratégicos (CGEE). 2016. *Desertification, Land Degradation and Droughts in Brazil*. DF, Brasília. https://www.cgee.org.br/documents/10195/734063/DesertificacaoWeb.pdf (in Portuguese)
[16] Mohinder Singh, N. K. T., Naveen Kumar, K. R. D., and Dehinwal, A. K. 2017. "Dry and Rainfed Agriculture—Characteristics and Issues to Enhance the Prosperity of Indian Farming Community." *BEPLS* 6 (10): 232.
[17] Ashalatha, K. V., Munisamy, G., and Bhat, A. R. S. 2012. "Impact of Climate Change on Rainfed Agriculture in India: A Case Study of Dharwad." *International Journal of Environmental Science and Development* 3 (4): 368-71.
[18] Beyer, M., M. Wallner, L., Bahlmann, V., Thiemig, J., Dietrich, and Billib, M. 2014. "Rainfall Characteristics and Their Implications for Rain-Fed Agriculture: A Case Study in the Upper Zambezi River Basin." *Hydrological Sciencies Journal* 61 (2): 321-43. https://www.researchgate.net/publication/274904292_Rainfall_characteristics_and_their_implications_for_rain-fed_agriculture_a_case_study_in_the_Upper_Zambezi_River_Basin.
[19] Alemaw1, B. F., and Simalenga, T. 2015. "Climate Change Impacts and Adaptation in Rainfed Farming Systems: A Modeling Framework for Scaling-Out Climate Smart Agriculture in Sub-Saharan Africa." *American Journal of Climate Change* 4: 313-29. https://www.researchgate.net/publication/281703004_Climate_Change_Impacts_and_Adaptation_in_Rainfed_Farming_Systems_A_Modeling_Framework_for_Scaling-Out_Climate_Smart_Agriculture_in_Sub-Saharan_Africa/link/58fad3370f7e9ba3ba503df7/download.
[20] Briguglio, L. 2003. "The Vulnerability Index and Small Island Developing States: A Review of Conceptual and Methodological Issues." In *Proceedings of the AIMS Regional Preparatory Meeting on the Ten Year Review of the Barbados Programme of Action*, Praia, Cape Verde. https://www.um.edu.mt/data/assets/pdf_file/.
[21] Brooks, N. 2003. "Vulnerability, Risk and Adaptation: A Conceptual Framework." *Tyndall Centre for Climate Change Research Working Paper* 38: 1-16. https://www.climatelearningplatform.org/sites/default/files/resources/Brooks_2003_TynWP38.pdf.
[22] Thornton, P. K., Jones, P. G., Owiyo, T., Kruska, R. L., Herrero, M., Orindi, V., Bhadwal, S., Kristjanson, P. M., Notenbaert, Omer-Bekele, A. M., and Abisalom, N. O. 2008. "Climate Change and Poverty in Africa: Mapping Hotspots of Vulnerability." *African Journal of Agricultural and Resource Economics* 2 (1): 24-44.
[23] Hahn, M., Riederer, A., and Foster, S. 2009. "The

Livelihood Vulnerability Index: A Pragmatic Approach to Assessing Risks from Climate Variability and Change—A Case Study in Mozambique." *Global Environmental Change* 19 (1): 74-88.

[24] Fávero, L. P. L., Belfione, P., Silva, F. L., and Chan, B. L. 2009. *Data Analysis: Multivariate Modeling for Decision Making* (2nd ed.). Rio de Janeiro: Elsevier Editora Ltda, 641. (in Portuguese)

[25] Guillaumont, P., and Simonet, C. 2011. *Designing an Index of Structural Vulnerability to Climate Change.* France: FERDI-Foundation for Studies and Research on International Development, 42.

[26] Ather, S. M., and Nimalathasan, B. 2009. "Factor Analysis: Nature, Mechanism & Uses in Social and Management Researches." *Journal of the Institute of Cost of Management Accountant of Bangladesh* 37 (2): 12-7. https://www.researchgate.net/publication/200564629.

[27] Wooldridge, J. M. 2010. *Introduction to Econometrics: A Modern Approach.* São Paulo: Cengage Learning. (in Portuguese)