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PRECIPITATION AND THE DETERMINATION CRITERION FOR STANDARD-YEARS

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Abstract

The purpose of the present study is to develop, based on the element of precipitation, the stages for determining standard-years in the state of Ceará, considering the application of the Tavares method (1976). As the selection criterion, a geostatistical spatialization of the data was also applied using the Kernel Smoothing estimator. The database employed is composed of 184 rainfall stations of the Cearense Foundation for Meteorology and Water Resources (FUNCEME), and comprises a 20-year time scale, between 1991-2010. The data were organized according to the criteria adopted by Tavares (1976), which were validated through tools of cross-validation and validation/prediction. After validation, the data were quantified through histograms and spatialized using the Kernel Smoothing estimator. By quantifying the histograms and analyzing the maps, the following years were selected as standard-years for the state of Ceará: 2005, as the dry year, 2004, as the usual year and 2009, as the rainy year.

Keywords: Standard-year; Geographical climatology; Kernel estimator.

PRECIPITAÇÃO E O CRITÉRIO DE ESCOLHA DE ANOS-PADRÃO

Resumo

A proposta deste estudo é desenvolver com base no elemento precipitação, as etapas para a eleição de anos-padrão ao estado do Ceará, considerando a aplicação do método de Tavares (1976). Como critério de escolha, fez-se uso também da espacialização geoestatística dos dados por meio do estimador Kernel Smoothing. A base de dados utilizada é composta de 184 postos pluviométricos da Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME), e compreende uma escala temporal de 20 anos, entre 1991-2010. Os dados foram organizados conforme os critérios adotados por Tavares (1976), sendo estes validados por meio das ferramentas de validação cruzada e validação/previsão. Feito a validação, os dados foram quantificados em histogramas e espacializados a partir do estimador Kernel Smoothing. Pela quantificação dos histogramas e análises dos mapas, foram selecionados como anos-padrão para o estado do Ceará: 2005, como ano seco, 2004, como ano habitual e 2009, como ano chuvoso.

Palavras-chave: Ano-padrão; Climatologia geográfica; Estimador Kernel.

PRECIPITACIÓN Y CRITERIO PARA ELEGIR AÑOS ESTÁNDAR

Resumen

El propósito de este estudio es desarrollar, en base al elemento de precipitación, las etapas de elección de años estándar, para el estado de Ceará, considerando la aplicación del método Tavares (1976). Como criterio de selección, la espacialización de datos geoestadísticos también se realizó utilizando el estimador Kernel Smoothing. La base de datos utilizada está compuesta por 184 estaciones pluviométricas de la Fundación Cearense de Meteorología y Recursos Hídricos (FUNCEME), y comprende una escala de tiempo de 20 años, entre 1991-2010. La organización de los datos siguió los criterios adoptados por Tavares (1976), que fueron validados a través de las herramientas de validación cruzada y validación / predicción. Después de la validación, los datos se cuantificaron en histogramas y se espacializaron usando el estimador Kernel Smoothing. Al cuantificar los histogramas y el análisis de los mapas, se seleccionaron como años estándar para el estado de Ceará: 2005, como el año seco, 2004, como el año habitual y 2009, como el año lluvioso.

Palabras-clave: Año estándar, climatología geográfica, estimador Kernel.

1. INTRODUCTION

The impact of climatic hazards on the geographic space is the focus of many studies. The analysis of intense climatic phenomena is of fundamental importance for society, given the impacts arising from these events.

When considering the analysis of these incidents, studies based on Geographical Climatology stand out, focusing on the valuation of deviations in the pace of succession regarding different types of weathers (MONTEIRO, 1971 and 1976), which provide tools for the application of methodologies that have as their purpose a greater reliability to the climatic data, focusing on the understanding of the atmospheric complex that causes such deviations, often classified as extreme.

An extreme deviation is considered a sharp variation in the climatic pace, being it positive or negative (TAVARES, 1976). Among studies regarding the identification of these deviations, the selection of standard-years stands out, which are fundamental for monitoring the variations present in the climatic pace of a given region.

The standard-year is an initial stage towards the development of a climatic characterization under the geographical scope. It refers to the selection of annual chronological samples, which represent "the different degrees of proximity to the 'usual' pace alongside those affected by irregularities in circulation (MONTEIRO, 1991, p. 38)". Such conception allows for both a quantitative understanding, through the annual, seasonal, monthly and episodic scales, as well as a qualitative one, by means of the process of genetic analysis, including the succession pace of the different types of weather.

As a fundamental stage for climate characterization, the choice of such years must be outlined under careful data treatment. In the present study, the selection process regarding standard-years was developed considering a statistical treatment around the method proposed by Tavares (1976), which offers a classification of 3 different types of standard-years - the dry, the usual and the rainy year -, which was carried out from a 20-year time scale data, in the 1991-2010 chronology.

Such proposition for the determination of standard-years is the initial phase for the development of a climatic characterization in the state of Ceará, based on the dynamic focus of Geographic Climatology. Therefore, this article aims to indicate the step-by-step for choosing standard-years according to the Tavares method (1976), presenting the calculations to achieve the final product, and going further by using geostatistics as a basis for the process spatialization in the classification as dry, usual and rainy years.

The state of Ceará was selected as the study site, which is located in the Northeast of Brazil (Figure 01), with a population of 8,452,381 inhabitants, and an area of 148,825.6 km², constituting the 4th territorial extension of the Northeast (IPECE, 2011). Its territory is 93% subject to the influence of semi-aridity, with high rates of evaporation/evapotranspiration and low rainfall indexes, with a predominance of the Hot Semi-Arid Tropical climate, which covers 98 of the 184 municipalities (IPECE, 2011). Thus, the relationship between the State and its climatic hazards, becomes the focus of studies whose role is to expand forms of forecasting and analysis of intense climatic phenomena that have repercussions on society.

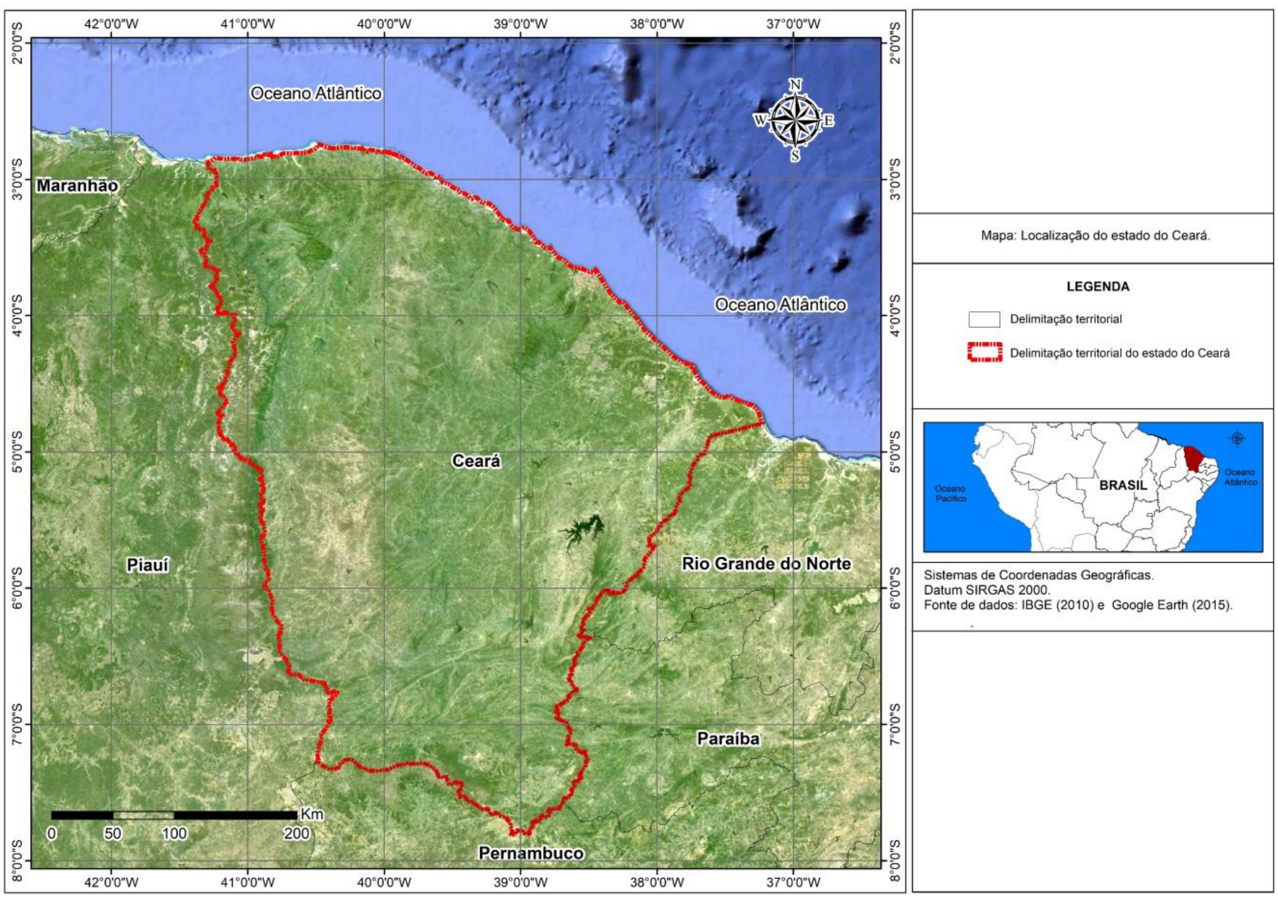


Figure 01 – Location of the study area. Source: Elaborated by the author.

2. METODOLOGY

Data collection was carried out using the rainfall data network of the Cearense Meteorology and Water Resources Foundation (FUNCEME). The data were organized according to the method proposed by Tavares (1976), corresponding to a 20-year time scale delimited between the years 1991 and 2010.

All 184 municipalities in Ceará are represented by rainfall stations. For this work, we highlight the main municipal stations for each of them (Figure 02).

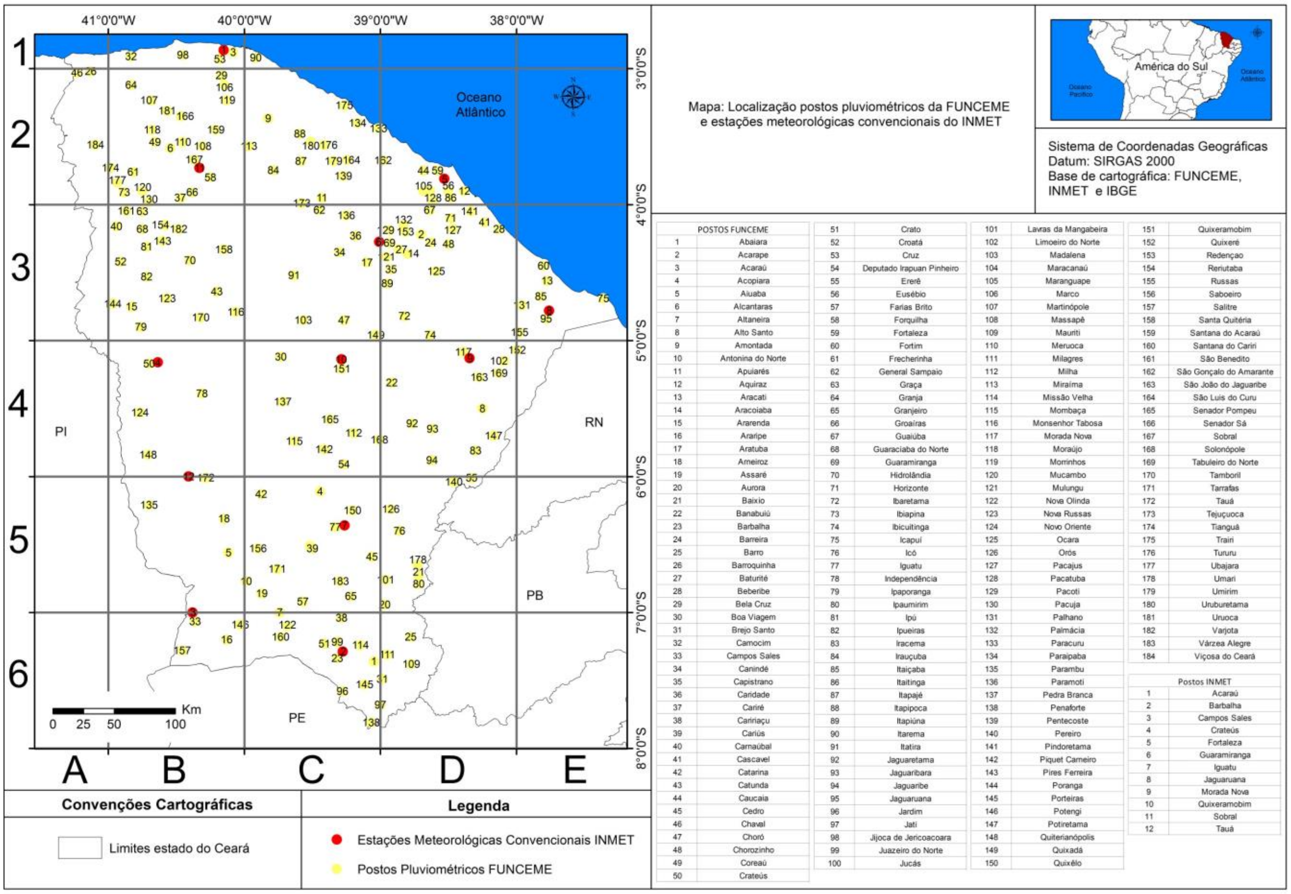


Figure 02 – Location of FUNCEME rainfall stations in the state of Ceará. Source: Elaborated by the author.

Certain flaws were observed in the series, requiring the application of a method to fulfill such gaps. We highlight the regional weighting method for correction of the monthly total failures, which was used in the application of the Tavares method (1976), provided in the following formula according to Barbosa Jr. (2000):

$$Py = \frac{\overline{Py}}{3}\left(\frac{P_{X1}}{\bar{P}_{X1}} + \frac{P_{X2}}{\bar{P}_{X2}} + \frac{P_{X3}}{\bar{P}_{X3}}\right)$$

Where Py is the missing monthly value ought to be corrected at a given station Y;

$\overline{Py}$ is the value of the average monthly precipitation for a given station Y;

P_{X1}, P_{X2} e P_{X3} are the precipitation values of the stations neighboring to Y;

$\bar{P}_{X1}, \bar{P}_{X2}$ e $\bar{P}_{X3}$ are the average monthly precipitation values of the stations neighboring Y;

As a criterion for choosing neighboring stations responsible for filling in the missing data at station Y, we searched for stations that did not differ between themselves and the missing station by over 10% (SILVA, 2006), in order to use data which are closer to the reality of the missing stations.

2.2. Example of application of the Tavares method (1976) for the selection of standard-years, considering the example of a rainfall station

After collecting and sorting the data, these were organized according to the chosen method for the selection of the standard-years. It should be noted that for the present article, the development stages of such a method are exemplified by the use of only one station, in this case the one located at the headquarters of the Municipality of Sobral, Ceará, under the coordinates -3.42 Latitude and -40, 21 Longitude. However, it is important to outline that for the determination of standard-years in the state of

Ceará, the steps performed were applied to all 184 rainfall stations considered in the survey.

The stages leading to the selection of the standard-years by Tavares (1976) are respected, as established below.

Initially, the rainfall data were collected, processed and organized around monthly totals, respecting their annual limits (Table 01).

Table 01 – Total monyhly precipitation in the years considered in the researcherd time scale. Source: FUNCEME (elaborated by the author).

SOBRAL	JAN	FEB	MAR	APR	MAY	JUNE
1991	62,1	133	169,1	222,4	125,2	9,7
1992	156,1	69,7	252,5	66,5	0	32
1993	29	76,7	54	187	32,9	15
1994	189,8	134,8	176,3	474	113	110
1995	128,5	233,5	126	285	131	16
1996	129,9	100	287,5	306,8	31,4	0
1997	45,8	61,1	128	146,3	29,3	2,5
1998	171	23,5	107	58,5	48	15
1999	139	154	334,8	224	227	15
2000	93,1	158,4	226	330	85	20,8
2001	55	254	141,6	321	62	30
2002	209	59,5	206,5	225,2	90,8	74
2003	101	289	520	122	87	16
2004	392	262	125	176	156	88
2005	39	138	177	218	71	29
2006	3	304	213,5	150,5	92,5	50
2007	2,2	255	209	288	76	21
2008	152	151	369	320	137	20
2009	100	209	181,5	298,3	331,2	108
2010	118,6	102,6	83	187,2	49	18
SOBRAL	**JULY**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
1991	0	0	0	0	0	0
1992	0	0	0	0	0	0
1993	10	0	0	0	0	3
1994	15	0	0	0	0	19
1995	3	0	0	0	0	0
1996	32,3	3,3	0	0	0	0
1997	0	0	0	0	0	0
1998	0	0	0	0	0	13,2
1999	6	0	0	0	57	84
2000	63	44	7,6	0	0	11,5
2001	0	0	0	0	0	8
2002	27,8	0	0	0	0	0
2003	3	0	0	0	0	18
2004	71	0	0	0	0	0
2005	0	0	0	0	0	3
2006	8	0	0	0	0	20
2007	0	0	0	0	0	71
2008	0	47	0	0	0	0
2009	38,5	0	0	0	0	0
2010	0	0	0	0	0	27

Such rainfall data were grouped into quarterly periods, corresponding to each of the seasons (Table 02). For better organization and in accordance to Tavares (1976), astronomical stations are not considered.

After grouping the data into quarterly periods, the average precipitation for each of the seasons was calculated, also generating a GENERAL AVERAGE precipitation value for the year (in Table 2):

Table 02 – Average quarterly and general precipitation for the years considered in the researched time scale. Source: Elaborated by the author.

SOBRAL	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Summer	121	159	53	167	163	172	78	101	209	159
Autumn	119	33	78	232	144	113	59	41	155	145
Winter	0	0	3	5	1	12	0	0	2	38
Spring	0	0	1	6	0	0	0	4	47	4
SOBRAL	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Summer	150	158	303	260	118	174	155	224	164	101
Autumn	138	130	75	140	106	98	128	159	246	85
Winter	0	9	1	24	0	3	0	16	13	0
Spring	3	0	6	0	1	7	24	0	0	9

SOBRAL	GENERAL AVERAGE
Summer	160
Autumn	121
Winter	6
Spring	6

Since we are using a sample selection, the focused chronological period must contain at least 10 years of data (TAVARES, 1976).

From the data outlined in Table 2, the PERCENTAGE DEVIATION of each season is calculated. For such calculation, the value of the QUARTERLY AVERAGE is subtracted by the value of the GENERAL AVERAGE. The result is the value that represents the AVERAGE DEVIATION (GERARDI E SILVA, 1981).

$$\text{AverageDeviation} = \text{QuarterlyAverage} - \text{YearlyGeneralAverage}$$

Through the AVERAGE DEVIATION, the PERCENTAGE DEVIATION was achieved, since the PERCENTAGE DEVIATION is the AVERAGE DEVIATION divided by the GENERAL AVERAGE of the year, multiplied by 100 (GERARDI AND SILVA, 1981). The results are outlined in Table 03.

$$\text{PercentageDeviation} = \left(\frac{\text{AverageDeviation}}{\text{YearlyGeneralAverage}}\right) \times 100$$

Table 03 – Precipitation percentage deviation in the years considered in the researched time scale. Source: Elaborated by the author.

SOBRAL	**DEVIATION PERCENTAGE**									
	1991	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Summer	-24	0	-67	5	2	8	-51	-37	31	0
Autumn	-2	-73	-35	92	19	-7	-51	-67	28	20
Winter	-100	-100	-47	-21	-84	88	-100	-100	-68	504
Spring	-100	-100	-82	14	-100	-100	-100	-21	743	-31
TOTAL	-226	-273	-231	89	-163	-11	-302	-225	734	492
SOBRAL	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Summer	-6	-1	90	63	-26	9	-3	40	2	-36
Auntumn	14	7	-38	16	-13	-19	6	31	103	-30
Winter	-100	47	-84	274	-100	-58	-100	148	103	-100
Spring	-52	-100	8	-100	-82	20	324	-100	-100	61
TOTAL	-144	-47	-25	252	-221	-49	228	119	108	-105

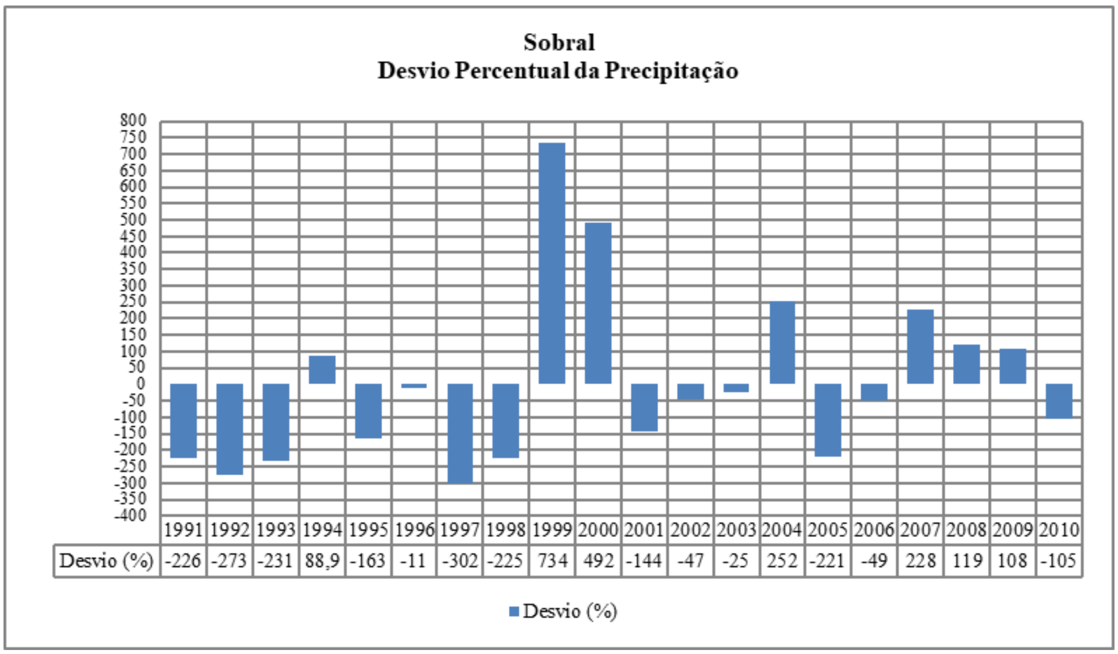


Figure 03 – Precipitation percentage deviation in the years considered in the researched time scale. Source: Elaborated by the author.

According to Tavares (1976), deviations close to 0 (zero) are considered as usual ones, those with great positive deviations are considered as rainy ones, and those with great negative deviations correspond as dry ones (Figure 03).

In order to group and better delimit the years of dry, usual and rainy representativeness, the creation of a DENDROGRAMA is made, carried out by the complementary tool of Microsoft Excel, free software Action 2.6 (Figure 04).

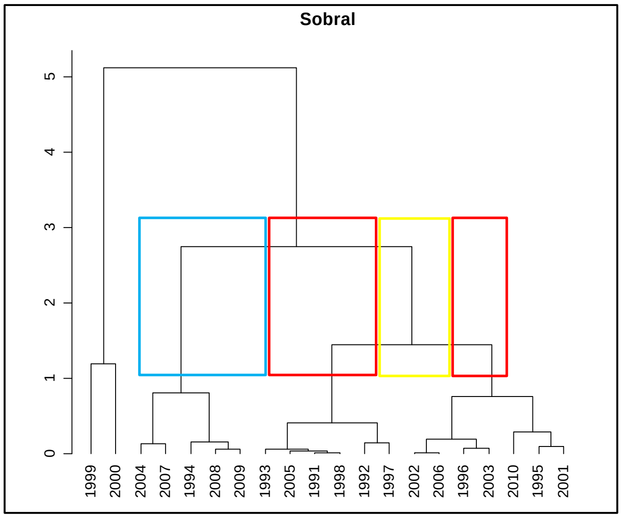


Figure 04 –Dendrogram. In red, dry years; in yellow, usual years; and in blue, rainy years. Source: Action 2.6 (elaborated by the author).

By means of the DENDROGRAMA, it is possible to systematize the data and organize the years of greatest similarity with one another, which allows for the classification as dry (marked in red), usual (marked in blue) and rainy (marked in blue) years. The dry years correspond to: 1993, 2005, 1991, 1998, 1992, 1997, 2010, 1995 and 2001; usual years correspond to: 2002, 2006, 1996 and 2003; and, lastly, rainy years correspond to: 1999, 2000, 2004, 2007, 1994, 2008 and 2009.

In the methodology proposed by Tavares (1976), the final step to be developed is the analysis of the dendrogram, as performed in the previous paragraph. However, when considering a larger set of rainfall stations, it is important to develop complementary analyzes, which for this study is done by means of a quantitative interpretation using histograms, and by the spatialization of the values resulting from the percentage deviation, through Smoothing kernel maps.

2.3. Complementary steps to the Tavares method (1976): data modeling through Kernel Smoothing

The Tavares method (1976) was applied up to the stage referring to the production of the precipitation percentage deviation values, throughout the entire base of 184 rainfall stations.

Cartographic production took place using the Kernel Smoothing estimator in a Gaussian prediction function, as indicated by Barbosa et al. (2014). Another step to be observed when using Kernel is the choice of the radius of influence (radius), which was established according to the standard size calculated by ArcMap 10.1, expressed in the following table:

Table 04 – Radius of influence considered for the production of Kernel Smoothing maps. Source: ArcMap (elaborated by the author).

Year	**1991**	**1992**	**1993**	**1994**	**1995**
Radius	0,41	0,56	0,32	0,32	0,48
Year	**1996**	**1997**	**1998**	**1999**	**2000**
Radius	0,41	0,41	0,40	0,36	0,36
Year	**2001**	**2002**	**2003**	**2004**	**2005**
Radius	0,39	0,32	0,32	0,33	0,35
Year	**2006**	**2007**	**2008**	**2009**	**2010**
Radius	0,41	0,39	0,41	0,39	0,41

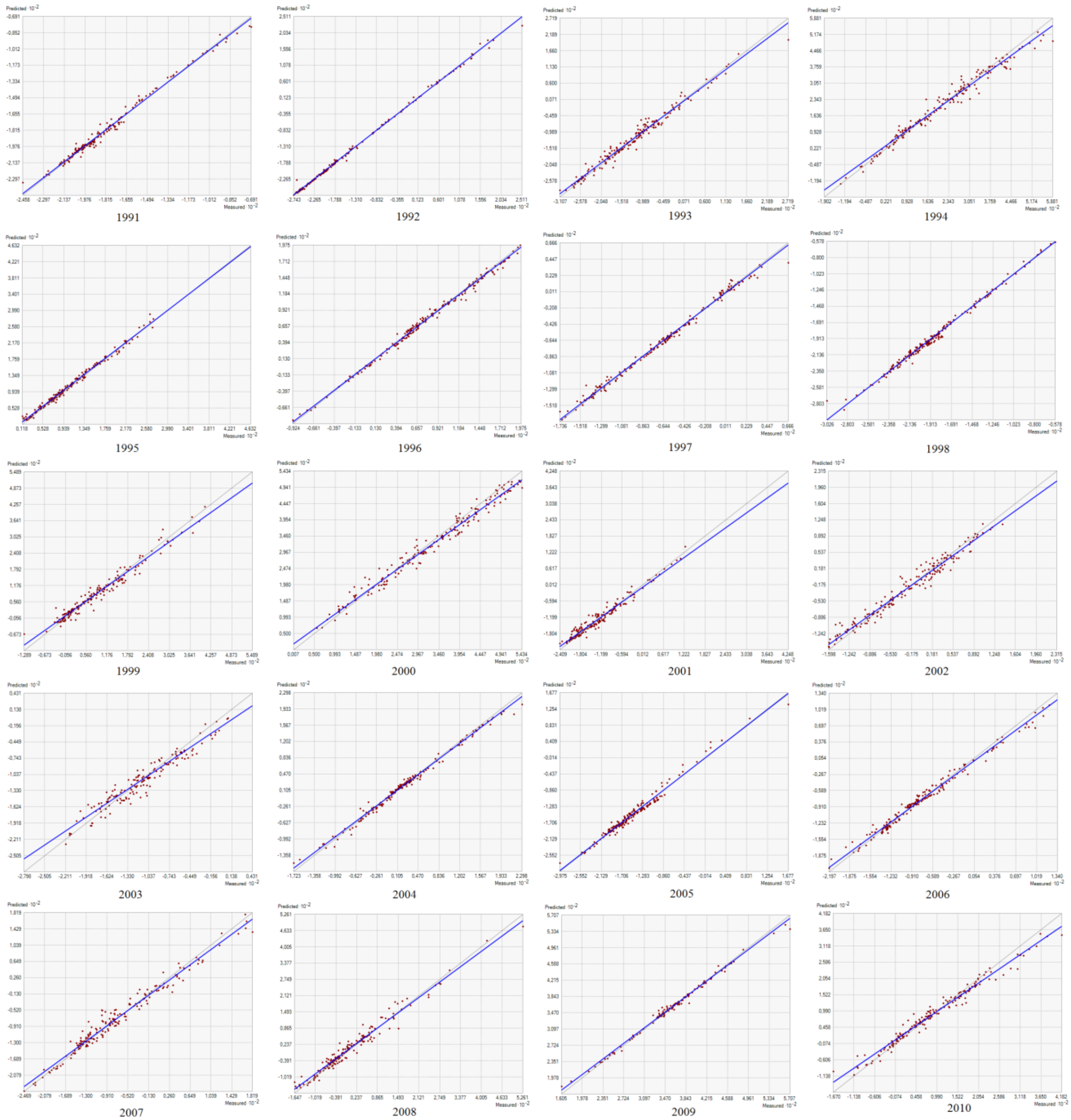
Before the final cartographic production, the data resulting from percentage deviation proposed by Tavares (1976) were analyzed for consistency through the production of boxplot graphs in the Action 2.6 software, and by means of the Cross Validation and GA Layer to Points - Validation/Prediction tools in ArcMap 10.1, consisting of essential stages for the development of a correct geostatistical modeling, as specified by ESRI (2013, p. 01):

> Before you produce the final surface, you should have some idea of how well the model predicts the values at unknown locations. Cross-validation and validation/prediction help you make an informed decision as to which model provides the best predictions. The calculated statistics serve as diagnostics that indicate whether the model and/or its associated parameter values are reasonable.

Thus, the percentage deviation data were analyzed based on cross-validation and endorsed by the validation/prediction tool. Also according to ESRI (2013), for the production of a better prediction model in the interpolation, the analysis of the Predicted and Normal *QQ Plot* graphs stand out, both present in the cross validation. Their purpose is to identify whether the developed model is correctly predicting. In this case, the Predicted graph verifies the data dispersion, and the *QQ Plot* graph shows their standard normal distribution (ESRI, 2013). Moreover, the interpretation of the graphs will take place as follows:

- Predicted Graph*:* when the blue line is closer to the black dashed line, it indicates that the data is good for use;
- Normal *QQ Plot* Graph: the blue dots should be more or less along the gray line.

The graphs generated to confirm the quality of the Kernel Smoothing interpolation model are shown in Figure 05.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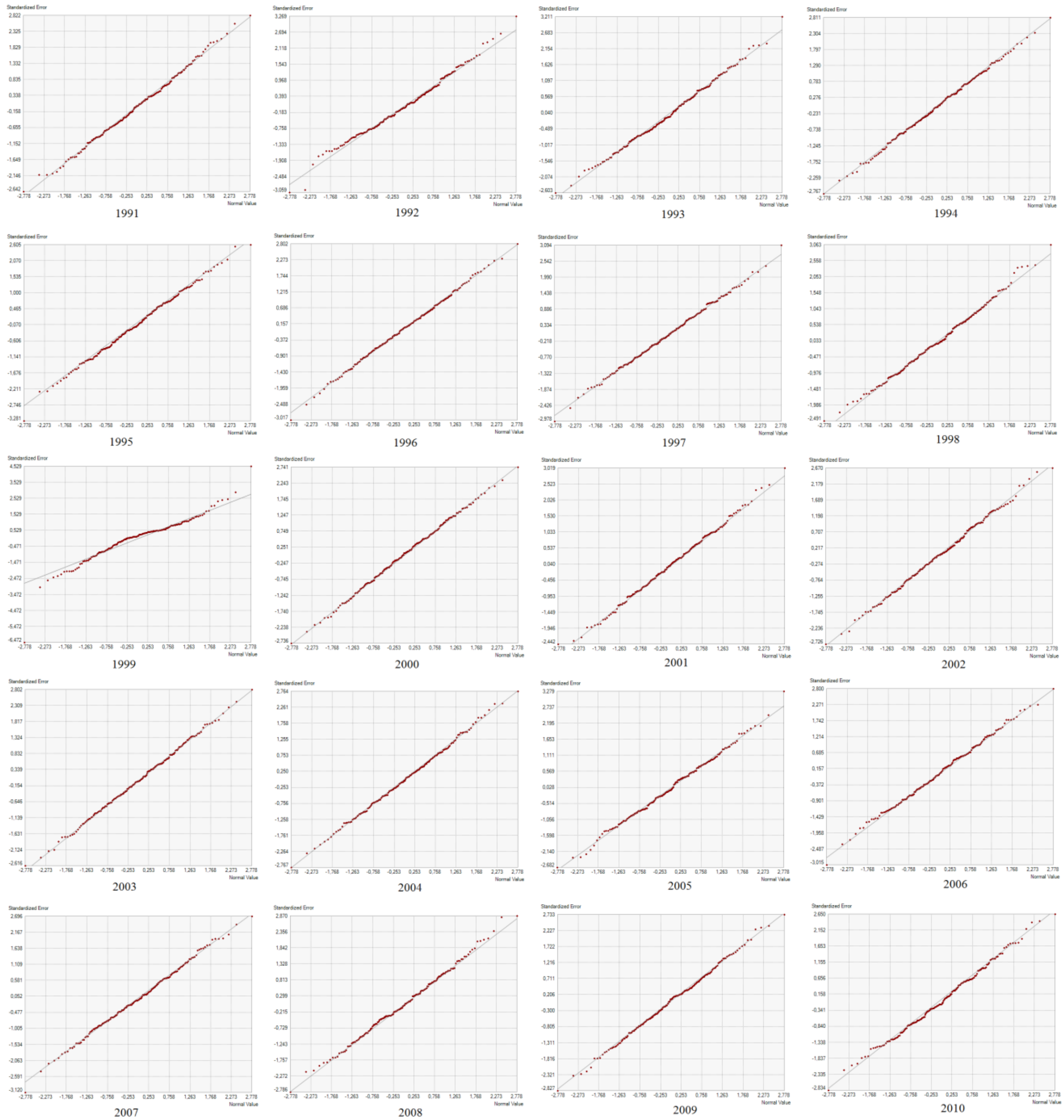

(b)

Figure 05 – Predicted validation graphs (a) and QQ Plot (b). Source: ArcMap (elaborated by the author.).

Once the maps were produced, considering the analyzes by boxplot, cross-validation and validation/prediction, the next step was to establish the criteria for classification as dry, usual and rainy conditions. The Symbology tool (symbology) was applied, classified according to the Equal Intervals method (equal intervals) considering the minimum and maximum limits of the percentage deviation data, which are representative of the 184 stations in the 20-year time scale. The result is expressed in Table 05.

Table 05 –Minimum and maximum limits of the percentage deviation data representative of the 1991-2010 series. The minimum value is highlighted in red, and the maximum deviation value of the series in the blue. Source: Elaborated by the author.

Values	**1991**	**1992**	**1993**	**1994**	**1995**
Minimum	-245	-274	-310	-190	11
Maximum	-69	251	271	588	463
Values	**1996**	**1997**	**1998**	**1999**	**2000**
Minimum	-92	-173	-302	-128	55
Maximum	196	66	-57	548	543
Values	**2001**	**2002**	**2003**	**2004**	**2005**
Minimum	-240	-159	-279	-172	-297
Maximum	424	231	43	229	167
Values	**2006**	**2007**	**2008**	**2009**	**2010**
Minimum	-227	-246	-240	152	-267
Maximum	140	181	547	570	640

The values of minimum and maximum limits of the previous tables are considered through the equal interval classification. The minimum value is -310, and maximum is 640 for the analyzed series. The next step is to delimit within the equal interval classification, those being representative classes of dry, usual and rainy patterns.

Initially, negative and positive values that are closer to 0 (zero) are registered, which are the usual values for the percentage deviation (Tavares, 1976). Afterwards, the values above the delimitation of the usual values are considered dry, if negative, and rainy, if positive.

The data range that best grouped the usual data pattern was established in the 4th class of delimitation by equal intervals, and the limits established were:

From -310 to -72.5 the class of dry standard-years / From -72.5 to 165 the class of usual standard-years / From 165 to 640 the class of rainy standard-years.

The elaboration of the maps was complemented by the production of histograms, which are representative of the classification of all 184 dendrograms from the rainfall stations used in this research. Through the use of histograms, it was possible to quantify the seasons classified as dry, usual and rainy for the entire time series employed.

3. RESULTS AND DISCUSSIONS

The choice of the Tavares method (1976) was based on the climate concept adopted by the author, which fits into the climate ideas attributed to Sorre (1951) and Monteiro (1971 and 1973), and whose main objective is to "[.. .] establish criteria for choosing standard-years, within a certain chronological period, to be studied through pace analysis " (TAVARES, 1976, p. 79).

From the analysis of the dendrograms, the following annual classification was achieved, which is outlined in the histograms in Figure 06:

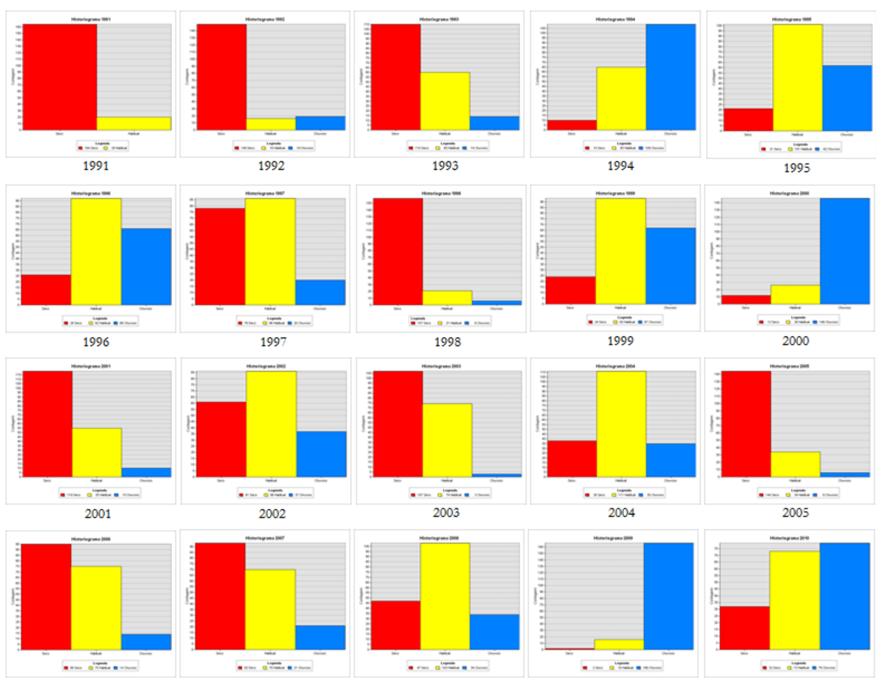

Figure 06 – Classification of years as dry (red), usual (yellow) and rainy (blue) from the interpretation of dendrograns. Source: ArcMap (elaborated by the author).

Considering a quantitative analysis of the histograms, the years 1991, 1992, 1993, 1998, 2001, 2003, 2005, 2006 and 2007 are classified as dry for the state of Ceará; the years of 1995, 1996, 1997, 1999, 2002, 2004 and 2008 as usual; and 1994, 2000, 2009 and 2010 as rainy.

According to the Smoothing Kernel maps, considering in the color scale the delimitation imposed by the classification of intervals equal to those of the percentage deviation data, Figure 8 illustrates the following classification for the state of Ceará, according to the 1991-2010 time scale.

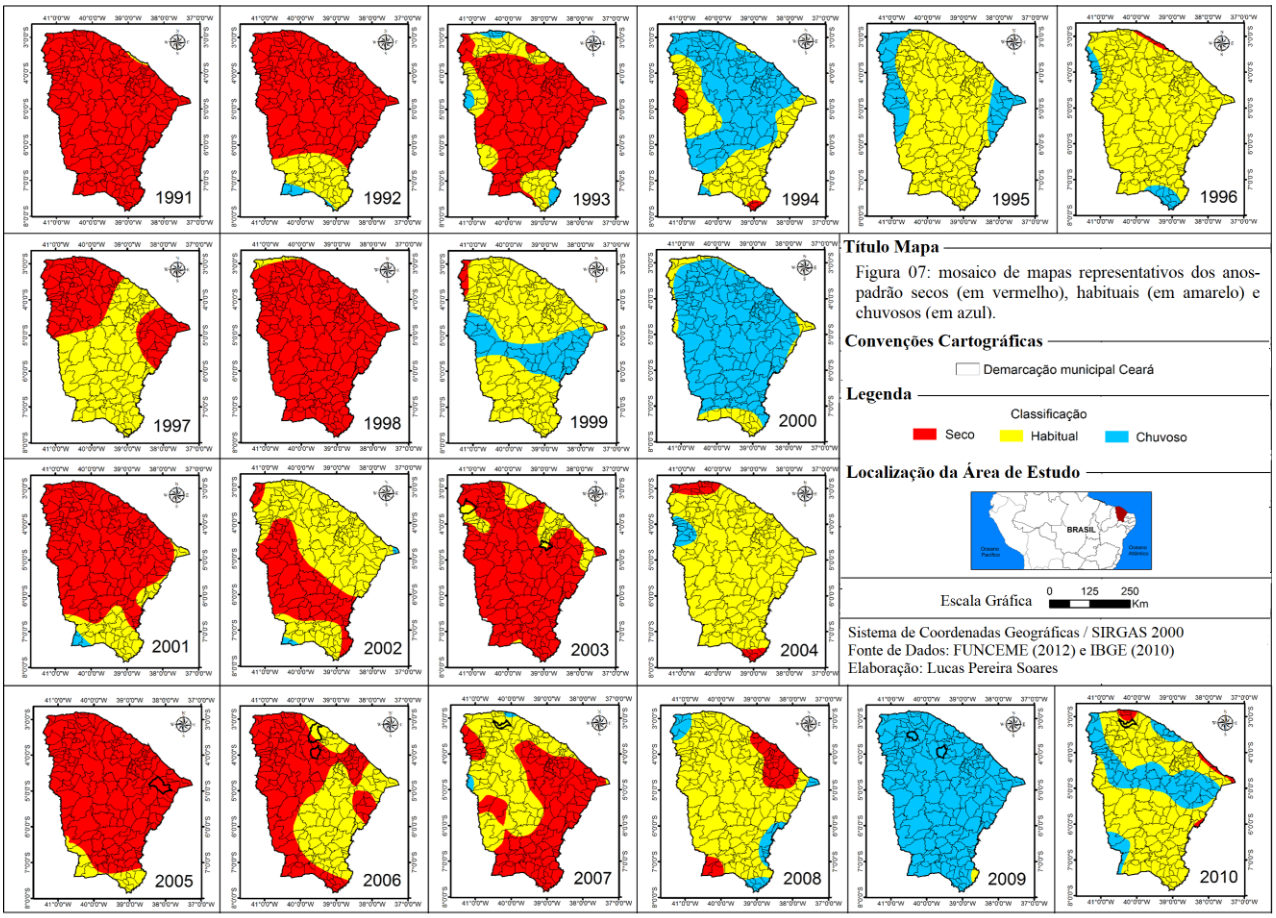

Figure 07 – Mosaic of maps representative of the standard-years as dry (in red), usual (in yellow) and rainy (in blue). Source: ArcMap (elaborated by the author).

By the methodology of equal intervals, the limits considered as dry, usual and rainy were delimited, thus the geostatistical spatialization of the precipitation percentage deviation data was developed, based on an interpolation by the Kernel Smoothing method, which resulted in the following interpretation presented in Figure 07:

- As dry years, 1991, 1992, 1993, 1998, 2001, 2003, 2005 stand out;
- As usual years, 1995, 1996,1999, 2004 and 2008;
- And as rainy years, 1994, 2000, 2009.

In some years, in view of the non-possibility of identifying the spatial pattern according to the selection between dry, usual and rainy, the classification of mixed years was adopted, especially during 1997, 2002, 2006, 2007 and 2010.

According to the histograms quantitative data and the interpretation of the Kernel Smoothing maps, the years of 2005, was selected as the dry pattern; 2004, as usual; and 2009, as rainy.

Since the determination of the standard-years is an initial step towards the development of a climatic characterization for the state of Ceará, the database of available satellite images – which are of interest to this research - was taken into account for determination through an analysis related to the quantification of atmospheric systems and air masses. Therefore, by analyzing the maps, the dry standard-year could be 1998, however the base of satellite images for 2005 was better. The same is true for 1996, which could be selected as the usual standard-year, yet, 2004 presented a higher quality for the satellite images.

4. FINAL CONSIDERATIONS

The Tavares method (1976) has a feature that considers the distribution of the annual rainfall regime, therefore it is not an approach that is based only on the annual totals of precipitation, including as it was put by Monteiro (1971, p. 04), whereas “annual totals should only be used for limited comparative purposes”.

This method for determining standard-years is not the simplest, as it requires the construction and analysis of dendrograms. When applied to many stations, it becomes laborious, also requiring a more accurate geostatistical analysis for the spatialization and production of maps. Since the values generated from the percentage deviation present many outliers to be corrected, and due to the presentation of negative data in the percentage deviation, they cannot be adjusted using the Log, Box-Cox and Arcsin transformations. However, it is a method that faithfully represents the rainfall dynamism, as it requires a particular analysis of all stations, in this case 184 dendrogram analyzes were made for this study, aiming to understand both the local rain dynamics - represented by each dendrogram - as well as a regional view of their behavior throughout the Ceará territory, when considering the whole.

Even with the application of a method that employs accuracy in the classification of dry, usual and rainy years, as well as a spatialization study of these classifications, there is some difficulty in identifying specific patterns in given years, especially considering areas with a relative territorial extension, as it is the case of Ceará, which concentrates a very large dynamic of convective clouds, forming convective systems that cause isolated rains.

Furthermore, it is also worth mentioning that all geostatistical treatment was carried out in order to comply with statistical standards that value the production of an appropriate interpolation model, thus avoiding arbitrary spatialization that makes it impossible to produce a surface that is accurately reliable with the data.

In future studies, the application and/or adaptation, of the Tavares method (1976) is encouraged, considering only the rainy period of the state of Ceará between February and May, thus being able to better dispose about the rains in the State, since the behavior of these in relation to the classification as rainy, usual or dry years, refers to the amount of precipitation in the months of the rainy season, emphasizing in this case the dynamics pertinent to the Intertropical Convergence Zone (ITCZ), which is an indicative of how abundant was the rainfall in Ceará.

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