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DROUGHT SEVERITY INDICES IN THE SEMIARID, PARAÍBA

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Abstract

The occurrence of annual and multiannual droughts in the Brazilian semiarid is a recurrent phenomenon that triggers a series of consequences, impacting the environment and the quality of life of the population inhabiting this region. Due to its location in the drought polygon, the Immediate Geographical Region of Monteiro – PB (REGIM does not diverge from this reality. Given the above, this research aims to correlate the DM, PNI, and RAI Severity Indices of Drought Events in the REGIM, through the historical rainfall series data, to classify the quantitative data on a monthly and annual scale and identify these cycles' Severity of Events (SDE) and consequently evaluate the variation of precipitation over time, identifying the dry and rainy periods. The research sourced monthly rainfall data from the Northeast Development Superintendence (SUDENE), National Institute of Meteorology (INMET), and Executive Agency of Water Management of Paraíba (AESA) to compose the spatial and temporal precipitation variability, which was calculated through the Normal Percentage Index – NPI (CUNHA, 2008), Decision Method – DM (GIBBS; MAHER, 1967) and Rainfall Anomaly Index – RAI (ROOY, 1965).

Keywords: Rainfall Standardization Indices – Ipp; Severity of Events – SDE; Water Resources.

Resumo / Resumen

INDICES DE SEVERIDADE DA SECA NO SEMIÁRIDO, PARAÍBA

A ocorrência de secas anuais e plurianuais no semiárido brasileiro é um fenômeno recorrente e que desencadeia uma série de consequências, com impactos no ambiente e na qualidade de vida da população que habita essa região. A Região Geográfica Imediata de Monteiro – PB (REGIM), localizada no semiárido paraibano, não difere dessa realidade, tendo em vista que está inserida no polígono das secas. Diante do exposto, está pesquisa tem o objetivo de correlacionar os Índices de Severidade dos Eventos da Seca MD, IPN e IAC na REGIM, através dos dados da série pluviométrica histórica, com intuito de classificar os dados quantitativos em escala mensal e anual e a identificação da Severidade dos Eventos (SDE) desses ciclos e, assim, avaliar a variação da precipitação no tempo, identificando os períodos secos e chuvosos. No desenvolvimento desta pesquisa, foram utilizados dados pluviométricos mensais da Superintendência do Desenvolvimento do Nordeste (SUDENE), Instituto Nacional de Meteorologia (INMET) e Agência Executiva de Gestão das Águas da Paraíba (AESA), para composição da variabilidade espaço-temporal da precipitação, que foi calculada através do Índice de Porcentagem Normal – IPN (CUNHA, 2008), Método dos Decis – MD (GIBBS; MAHER, 1967) e Índice de Anomalia de Chuva – IAC (ROOY, 1965).

Palavras-chave: Índices de Padronização Pluviométrica – IPP; Severidade dos Eventos – SDE; Recursos Hídricos.

ÍNDICES DE SEVERIDAD DE LA SEQUÍA EN EL SEMIÁRIDO, PARAÍBA

La ocurrencia de sequías anuales y plurianuales en la región semiárida brasileña es un fenómeno recurrente que desencadena una serie de consecuencias, con impactos en el medio ambiente y en la calidad de vida de la población que habita esa región. La Región Geográfica Inmediata de Monteiro - PB (REGIM), ubicada en la región semiárida de Paraíba, no difiere de esta realidad, considerando que se inserta en el polígono de sequía. En vista de lo anterior, esta investigación tiene como objetivo correlacionar los Índices de Severidad de los Eventos de Sequía MD, IPN e IAC en REGIM, a través de datos de la serie histórica de precipitaciones, con el fin de clasificar datos cuantitativos a escala mensual y anual e identificar la Severidad de los Eventos (SDE) de estos ciclos y, así, evaluar la variación de la precipitación en el tiempo, identificando los períodos seco y lluvioso. En el desarrollo de esta investigación, se utilizaron datos de precipitaciones mensuales de la Superintendencia de Desarrollo del Nordeste (SUDENE), el Instituto Nacional de Meteorología (INMET) y la Agencia Ejecutiva de Gestión Hídrica de Paraíba (AESA) para componer el espacio. la variabilidad temporal de la precipitación, que se calculó mediante el Índice de Porcentaje Normal - IPN (CUNHA, 2008), el Método de Deciles - MD (GIBBS; MAHER, 1967) y el Índice de Anomalía de la Lluvia - IAC (ROOY, 1965).

Palabras-clave: Índice de Estandarización de Lluvia – Ipp; Severidad de Eventos – SDE; Recursos Hídricos.

INTRODUCTION

The occurrence of annual and multiannual droughts in the Brazilian semiarid region is one of the main problems affecting biodiversity and the quality of life of the local population. The lack of rainfall that has affected this area has contributed to the reduction of surface and groundwater reserves, compromising the water supply of many cities and rural communities.

Drought refers to the lack or reduction of rainfall over time in a given place, whose onset is complex to detect. Therefore, its impacts are multiple and severe and may cause direct and indirect harm to the environment, economy, and society, which, in some cases, contributes to the acceleration of the migration process of affected families (MAGALHÃES, 2016; HAGENLOCHER et al., 2019; MEZA et al., 2019).

Thus, knowledge of climate characteristics in the Northeast region of Brazil (NEB) and their projections is essential as they show changes in precipitation and temperatures, a fact that is closely associated with water availability and crop adaptation conditions (SALES et al., 2015; GUIMARÃES et al., 2016).

According to Costa and Silva (2017), drought monitoring can be carried out using climatic indices, which describe dry and rainy periods, to understand the behavior of rains and the climatic variability of a location, state, or region and thus predict the severity of these phenomena and their impacts.

During recent decades, the use of Drought Indices has intensified in order to demonstrate methods of rainfall, temperature, and humidity analysis, with an emphasis on the following methods: Palmer Drought Severity Index (PDSI) (PALMER, 1965); Bhalme and Mooley Drought Index (Bhalme & Mooley Drought Index) (BHALME; MOOLEY, 1980); Lamb Rainfall Departure Index (LRDI) (LAMB et al., 1986); The Percent of Normal Index (PNI) (CUNHA, 2008); Decision Method – DM (GIBBS; MAHER, 1967); Rainfall Anomaly Index (RAI) (ROOY, 1965); and the Standardized Precipitation Index (SPI) (McKEE et al., 1993).

The PNI, DM, and RAI are foremost among the Drought Indices above, as they have advantages such as variable environmental data. The most used is rainfall, which facilitates the development of the research and analysis herein, given that it is hard to obtain historical series of other climatic variables with at least 30 years of data for Brazilian conditions (LIMA, 2016).

The PNI has the most straightforward calculations and can be applied to different time scales, usually between a month (or a set of months) to up to a year. However, its effects may be misinterpreted as the standard data used in the calculations may vary over time in the study area (NDMC, 2020).

According to Maniçoba et al. (2017), the RAI optimizes the visualization of the degree of rainfall variation around the climatological norm, acting as a good climatic indicator of rainfall variability.

There are different classifications of droughts, including meteorological approaches, which are shaped by lack of rainfall and the duration of aridity of a given environment, persisting for a month or more, with constant levels of rainfall below the average rainfall values for the dry period (NORONHA et al., 2016).

In turn, hydrological drought is related to a low available water volume, including groundwater, reservoirs, and rivers. Agricultural drought is also notable, determined by the lack of water in the soil for plant development, which makes the water supply to crops insufficient to replace the losses by evapotranspiration (DUARTE et al., 2018). In addition, socioeconomic drought interconnects human production openly with agricultural production and includes the direct and indirect impacts on agricultural production and other economic activities (FERNANDES et al., 2009).

Deforestation, disorganized crop practices, burning, irregular irrigation, and pollution have intensified the environmental degradation process in the semiarid region of Paraíba state. In addition to these factors, drought has increased due to the numerous factors outlined, further aggravating its historical context.

Droughts have worsened in Paraíba's semiarid region in recent decades, attracting the attention of researchers who are analyzing the phenomena to limit these factors, especially since the Immediate Geographical Region of Monteiro – PB (REGIM) is in the drought polygon.

This study's spatial cut of analysis is the semiarid region of Paraiba, which presents wide rainfall variability, hindering the development of agricultural activities. By predicting the climatic behavior in the region, this research has the potential to guide local managers, farmers, and other development agencies in the state, indicating the months with a trend of climatic anomaly, either dry or rainy, thus guiding planning to avoid natural disasters, crop losses, and better local management.

Given the above, the study aims to correlate the Severity Indices of Drought Events (DM, PNI, and RAI) in REGIM using the historical rainfall series data to classify the quantitative data on a monthly and annual scale and identify the Severity of Events (SDE) of these cycles. Additionally, it examines precipitation over time, identifying the dry and rainy periods.

MATERIAL AND METHODS

STUDY AREA

The study area was the REGIM, located in the State of Paraíba, which is part of the Intermediate Geographical Region of Campina Grande and composed of seven municipalities (Camalaú, Monteiro, Ouro Velho, Prata, São João do Tigre, São Sebastião do Umbuzeiro and Zabelê). Their population was estimated by the Brazilian Institute of Geography and Statistics (IBGE) at 56,699 inhabitants and a total area of 3,237,538 km² on July 1, 2017.

PLUVIOMETRIC DATA

This research used the monthly rainfall data from the Northeast Development Superintendence (SUDENE), National Institute of Meteorology (INMET), and Executive Agency for Water Management of Paraíba (AESA) to create the spatiotemporal variability of the REGIM's precipitation.

Thirty-one years of temporal precipitation data were collected in six rainfall stations located in the REGIM. Thus, it was possible to determine the monthly and annual rainfall; however, there were failures in the rainfall data for a few months from the rainfall stations. Therefore, statistical methods of regional weighting were used to fill gaps and continue the research.

STATISTICAL MODELING "FILLING IN FAULTS"

The regional weighting statistical method was used to fill gaps in the historical rainfall series, according to Equation 1.

$$PX = \frac{1}{n-1} * \left(\frac{PA}{PAm} + \frac{PB}{PBm} + \frac{PC}{PCm} + n\right) * \mathrm{PXm} \qquad \text{(Equation 1)}$$

Where: PXm, PAm, PBm and PCm are the average precipitations at stations X, A, B, and C, respectively; PX is the precipitation to be determined at station X; and PA, PB, and PC are the precipitations at stations A, B, and C, respectively, in the time interval referring the precipitation to be determined at station X.

This method estimates the rainfall that occurred at the failed rainfall station, considering it similar to the rainfall in neighboring stations. The proportionality factor is the function of the average rainfall at these stations, considering the average rainfall at the failed station itself. This method elects at least three adjacent stations with no data, which must be located in climatic regions similar to the failed station.

After the failure filling procedure, the Double Mass method was applied (Figure 1) to prove the linearity of the predicted statistical model. Therefore, the approximate alignment of points on a given graph indicates a proportionality between the data of the two stations in question.

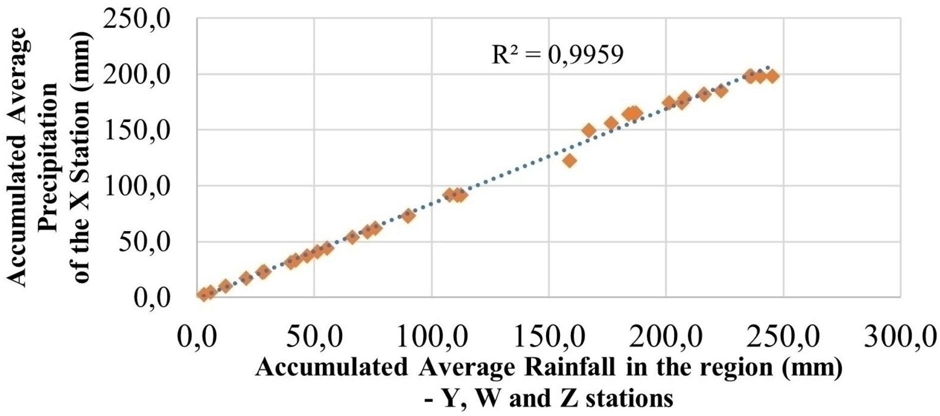

Figure 1 - Example of the Dual Mass Analysis mode. Source: Prepared by the authors.

DROUGHT INDICES

The three drought indices were calculated using the historical time series, aided by Microsoft Excel 2016 spreadsheets.

DECISION METHOD – DM

The DM was determined by grouping the means for each analyzed period in ascending order. From the cumulative frequency distribution, the series was divided into ten equal parts (deciles). The classification of this method was based on Gibbs and Maher (1967). According to Lima (2016), it determines the probability of an event occurring and qualitatively defines the climatic anomaly.

RAINFALL ANOMALY INDEX – RAI

The duration analysis of the dry and wet periods was performed by calculating the RAI (FREITAS, 2005) obtained from the equations and according to Table 1.

$$IAC = 3\left[\frac{(N-\overline{N})}{(\overline{M}-\overline{N})}\right]\text{: For positive anomalies (Equation 2)}$$

$$IAC = -3\left[\frac{(N-\overline{N})}{(\overline{X}-\overline{N})}\right]\text{For negative anomalies (Equation 3)}$$

In which:
N = Current monthly rainfall (mm);
$\overline{N}$= Average monthly rainfall of the historical series (mm);
$\overline{M}$= Average of the ten largest monthly rainfall in the historical series (mm);
$\overline{X}$= Average of the ten lowest monthly rainfall in the historical series (mm).

Gibbs and Maher (1967)		Proposed	
DM	Severity of events	DM	Severity of events
10 - 9	Very wet.	10	Extremely wet
8 - 7	Wet	9 - 8	Very wet.
6 - 5	Close to normal	7 - 6	Wet
4 - 3	Dry	5 - 4	Dry
2 - 1	Very dry.	3 - 2	Very dry.
-	-	1	Extremely dry

Table 1 - Severity Classes of the Rainfall Anomaly Index (RAI) events. Source: Araújo, et al. (2014) (2009).

In recent years this method has been used in several studies to define the rainfall during droughts and the characteristics of a given region (DINIZ et al., 2020; NASCIMENTO et al., 2020; NERY; SIQUEIRA et al., 2020).

NORMAL PERCENTAGE INDEX – PNI

The PNI provides simplicity in its calculations and can be employed for different time scales, changing most often between a month or a set of months up to a year (NDMC, 2020)

For the calculation of the PNI, Cunha (2008) expresses in percentage the ratio between the current precipitation and the normal precipitation (average of 26 years) of a region, using Equation 4.

$$IPN = \frac{PActual}{PNormal} \qquad \text{(Equation 4)}$$

where in:

PNI = Normal Percentage Index;

PActual = rainfall at a given location (mm);

PNormal = Average rainfall of the analyzed period (mm).

Finally, once the three Drought Indices had been developed, a new method was proposed for the REGIM to understand the dry or rainy periods through the data set.

ADAPTATION OF DROUGHT METHODS IAC, DM, AND PNI TO THE REGIM

The analysis of the results of the various drought indices was considered difficult to understand. Therefore, we sought to evaluate the events' degree of severity based on the classifications proposed for each of the indices evaluated. These classifications were used to verify the frequency of the different drought SDE of the indices applied to the REGIM. It is noteworthy that the methodology was adapted to the time frame, given that many authors suggest that there should be more than 30 years of data (LIMA, 2016; SILVA et al. 2020). The new classification demonstrated that this adaptation is possible using the existing data since a historical series of 31 years was used for the research in question.

The number of classes of the PNI and DM indices was adapted for better visualization of the data; thus, the standardization in the classification system had six SDE classes to fit the RAI classes and obeyed the same parameters, namely: Extremely wet (EW), Very wet (VW), Wet (W), Dry (D), Very dry (VD) and Extremely dry (ED).

Table 2 presents the drought classification suggested by Araújo et al. (2009) and the new research proposal. Following the RAI model, the parameters analyzed were modified. Formerly classified with values ranging from 4 to -4, the new values were between -4.1 to 4.1, equalizing the values of the classes. Therefore, the number of classes remained the same, preserving the same pattern as the new classification proposed for the DM and PNI, giving the Drought Index (DI) more objectivity.

2010; Araújo *et al.* (2009)		Proposed	
DM	**Severity of events**	**RAI**	**Severity of events**
From 4 above	Extremely Wet	4,1 ≥	Extremely wet
2 to 4	Very wet.	2,1 ≤ 4	Very wet.
0 to 2	Wet	0,1 ≤ 2	Wet
0 to 2	Dry	-0,1 ≤ -2	Dry
2 to 4	Very dry.	-2,1 ≤ -4	Very dry.
From -4 below	Extremely dry	≤ -4,1	Extremely dry

Table 2 - Relationship between the RAI values of Araújo et al. (2009) and those proposed by the authors. Prepared by the authors.

Table 3 shows Gibbs and Maher's (1967) drought classification (1967) and the proposed categorization. In the DM model proposed in Table 3, new classes are added considering the maximum and minimum extreme values, removing the normality proposed by Gibbs and Maher (1967). Therefore, these new suggested values in the possible results require greater attention when the findings demonstrate positive or negative extremes.

	RAI RANGE	CLASSES OF SEVERITY OF EVENTS
	From 4 above	Extremely wet
Table of contents	2 to 4	Very wet.
ANOMALY TYPE	0 to 2	Wet
Rain	0 to 2	Dry
IAC	2 to 4	Very dry.
	From -4 below	Extremely dry

Table 3 - Relationship between DM values and those proposed by the authors

Table 4 shows the PNI classification suggested by Cunha (2008) and the classification proposed in the present study, in which different numerical intervals were adopted for each dry SDE class. It was reformulated according to the previous DM and RAI classes, in which these indices were classified, especially the SDE rainfall parameters (low to extreme rainfall) and the removal of the normal class. Thus, this new approach presents wet event values that did not exist in the previous PNI.

Cunha (2008)		**Proposed**	
PNI	**Severity of events**	**PNI**	**Severity of events**
PNI ≥ 0.85	Normal	PNI ≥ 1.51	Extremely wet
0.75 ≤ PNI < 0.85	S1 Moderate drought	1.26 ≤ PNI < 1.50	Very wet.
0,50 ≤ PNI < 0,75	Severe drought	1.01 ≤ PNI <1.25	Wet
PNI < 0.50	S3 Extreme Drought	0.76 ≤ PNI < 1.00	Dry
-	-	0,51 ≤ PNI < 0,75	Very dry.
-	-	PNI < 0.50	Extremely dry

Table 4 - Relationship between Cunha's (2008) PNI values and those proposed by the authors. Prepared by the authors..

After analyzing the database and its classification in the monthly and annual time scales, Table 5 presents the new methodology proposed for identifying SDEs.

STANDARDIZATION	**THE PROPOSED SEVERITY OF EVENTS**		
	DM	**RAI**	**PNI**
Extremely wet	10	4,1 ≥	PNI ≥ 1.51
Very wet.	9-8	2,1 ≤ 4	1.26 ≤ PNI < 1.50
Wet	7-6	0,1 ≤ 2	1.01 ≤ PNI <1.25
Dry	5 4	-0,1 ≤ -2	0.76 ≤ PNI < 1.00
Very dry.	3-2	-2,1 ≤ -4	0,51 ≤ PNI < 0,75
Extremely dry	1	≤ -4,1	PNI < 0.50

Table 5 - Standard for the classification of DM, RAI and PNI Drought Indices.

PROPOSAL FOR A METHODOLOGICAL APPROACH TO THE CLASSIFICATION OF THE RAINFALL STANDARDIZATION INDEX ON A MONTHLY AND ANNUAL TIME SCALE

Thus, a qualitative classification was used in a quantitative classification, in which each index's results were analyzed for each year of the period in question, according to the Standardized Precipitation Index (SPI) classification. With this new arrangement, each index receives a rainfall scale according to the rainfall SDE in the region. Finally, these values will be summed, generating a score.

Therefore, between the six indices, the classification may range from "Emergency Drought" to "Rainfall Emergency." So, the classification parameters were applied on the monthly and annual scales to understand the results better.

As explained in Table 5, to create the drought classification system, it was considered that all the indices have the same proposed drought SDE. This overall value was used to determine the SDEs for all the months and years in the study period.

By correlating the drought indices analyzed, a new classification of the drought situation was proposed for each method in this study. Although each index has its own methodology, they have the same value, which was used to create the classification based on the drought indices, facilitating the final result by correlating the three indices.

Next, values for drought indices were delimited, based on the possible sum of rainfall scales, and named the Rainfall Standardization Index (RSI), as shown in Table 1, together with some combinations of SDE drought classes and their classification.

The possible combinations of the PNI, DM, and RAI indices defined this IPP classification. In the possible scenarios, they may have similar or different responses. Thus, the data set analyzed was divided into six classes (Table 5) ranging from "Extremely dry" to "Extremely wet." This parameter was split into 20 scores.

Each class's values were precisely determined by the set of possible results presented by the indices in Table 5. Every grade was named in the proposed new classification. Therefore, the proposed Rainfall Standardization Index was divided into six classes: Extreme Drought (ED), Severe Drought (SD), Normal Drought (ND), Normal Rainfall (NR), Severe Rainfall (SR), and Extreme Rainfall (ER).

Standardization Index of Rainfall Measurement	Rainfall Scale	PNI	DM	IAC
Extreme Drought	-10	ED	ED	ED
	-9	ED	ED	VD
Severe Drought	-8	ED	VD	VD
	-7	VD	VD	VD
	-6	VD	VD	D
	-5	ES	VD	D
Normal Drought	-4	VD	D	D
	-3	D	D	D
	-2	D	D	W
	-1	VD	D	W
Normal Rainfall	1	D	W	W
	2	W	W	W
	3	W	W	VW
	4	D	W	VW
Severe Rainfall	5	W	VW	VW
	6	VW	VW	VW
	7	VW	VW	EW
	8	W	VW	EW
Extreme Rainfall	9	VW	EW	EW
	10	EW	EW	EW

Table 6 - Proposed combinations of SDE classes to determine the Rainfall Standardization Index score.ED = Extremely dry; VD = Very dry; D = Dry; W = Wet; VW = Very wet; EW = Extremely wet. Prepared by the authors.

Table 6 presents each class, and their respective rainfall scales, defined as follows: Extreme Drought (scales -10 and -9) considers that when three matching results occur, that is, ED in all indices, the rainfall scale will be -10. Therefore, the scale of -9 is used when two of the three indices are ED and one VD.The Severe Drought rainfall scale has four grades ranging from -8 to -5. Notably, class -8 takes two indices into account: VD and ED. All the indices for -7 are VD, whereas the -6 classification has two VD and one D. Lastly, the -5 scale is assigned when the indices vary, being ED, VD, and D. In this case, the classification index is attributed to the variable that is in the middle.

The Normal Dry classification has grades ranging from -4 to -1; the -4 class is assigned when there are two D and one VD. When all the indices are D, the class is -3, the rainfall scale -2 has two D and one W, and score -1 is used when the indices have different values, such as VD, D, and W.

The Normal Rainfall class varies between scales 1 to 4, in which: 1 has two W indices and one S; in scale 2, all the indices are W; 3 is composed of two W and one VW, and grade 4 is used when D, W, and VD are present.

The penultimate class, Severe Rain, has four scales ranging from 5 to 8: scale 5 has the VW and W indices. On scale 6 all indices are W; while 7 has two W and one EW. In scale 8, the variables W, VW, and EW appear in different indices.

The final class, Extreme Rain, has two scales: 9, which is used when two ED and one VD occur, and 10, when all indices are EW. Thus, when applying the RSI classification system in the proposed monthly and annual time scale, it was sought to verify the periodicity of the most extreme anomalies and a possible pattern in the time series. Hence, the classification system permits the examination of drought conditions and the identification of the months and years with more extreme indices, namely "Rain or Drought Emergency," and observes their relationship in the study's chronological sequence, verifying its variation.

RESULTS AND DISCUSSION

Figure 2 indicates two predominant seasons in the region, one with five rainy months and another with seven dry months. When analyzing the data obtained, it is evident that the rainy season occurs between January and May, with March being the most representative, reaching an average rainfall of 116 mm. In contrast, the dry period occurs between June and December; September is the driest month, with 3 mm.

Around 78% of precipitation occurs in the first five months of the year, and the remaining seven months are in the dry period, with 22% of the year's rainfall. The latter are months with very scarce rainfall in the region, with volumes of 32 mm at most.

Thus, Souza et al., (2017) affirm the importance of increasing knowledge of the NEB's interannual and seasonal precipitation variability so that public policies are defined to maintain and preserve water resources.

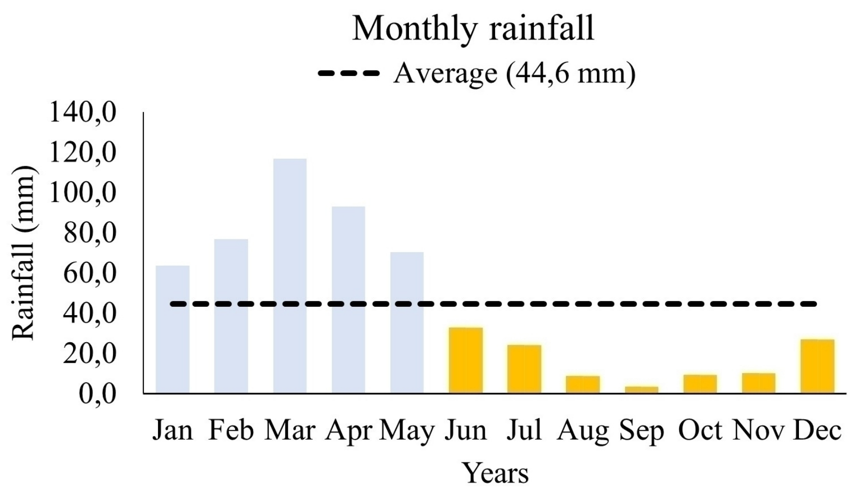

Figure 2 - Monthly precipitation rainfall (mm) of the 31 years of REGIM. Prepared by the authors.

The results of the SDEs (IAC, PNI, and DM) are shown in monthly and annual time scales for REGIM – PB. Thus, according to Table 7, the DM had extreme variations with four months of ED and EW. In addition, it was observed that none of the indices presented the parameters C and W in this method.

On the other hand, the RAI and PNI had more consistent results, with a similarity between the months or very close. In this sense, an analysis of the SDE indicated that the RAI and PNI had eight months or 66.6%. The BFI with the DM only had one month, or 8.3%, and the PNI had DM for this region for two months or 16.6%. Thus, the RAI and PNI are closer to reality on a monthly scale.

Months	Severity of events					
	IAC		DM		PNI	
January	1.3	W	7	VW	1.42	W
February	2.2	MU	8	EW	1.72	VW
March	4.9	EW	10	EW	2.61	EW
April	3.2	VW	9	EW	2.08	VW
May	1.7	W	8	EW	1.57	VW
June	-1.0	D	6	VD	0.74	W
July	-1.7	D	4	VD	0.54	D
August	-2.9	VD	2	ED	0.19	VD
September	-3.4	VD	1	ED	0.07	ED
October	-2.9	VD	3	ED	0.21	VD
November	-2.8	VD	3	ED	0.23	VD
December	-1.4	D	5	VD	0.61	D

Table 7- Monthly classification of SDEs on the scale from 1990 to 2020, according to the new proposed classification. ED = Extremely Dry; VD = Very Dry; D = Dry; W = Wet; VW = Very Wet; EW = Extremely Wet. Prepared by the authors.

Table 7 shows that each month has its peculiarity in the different indices, highlighting the proximity between one or more indices, following approximately the same SDEs. Thus, the proposed rainfall scale demonstrates information attributed to the region, in which it is possible to delimit the Standardization Index of Monthly Rainfall.

Therefore, the methods and classification used for the indices with similar results are presented in Figure 3, establishing two distinct periods. The first is from January to May, considered rainy months that vary in scale from NW to EW, with March peaking with the highest PNI.

In contrast, the other months have droughts ranging from ND to ED; September has the lowest rainfall value. Furthermore, March and December stand out as the end of the rainy and dry periods, respectively, and, consequently, the months of most significant water shortage showing results identical to the temporal rainfall in Figure 2.

Therefore, water plays a fundamental role in the development of the whole society, performing not only ecological but also economic and social functions (CALADO et al., 2020).

Given the results obtained, it is essential to manage this region's water resources based on the knowledge of the stations with the highest and lowest water subsidies in the area under study. Public policies that preserve and prioritize water, through the creation of cistern methods in several REGIM locations, are necessary since it is in a semiarid region, requiring water reserves in the months of a lower abundance of rainfall.

Plate cisterns capture rainwater efficiently, justifying their importance for regions susceptible to drought due to their economic viability, easy management, and construction. There is also the possibility of job creation for local residents, even if temporary, to build these reservoirs (PEREIRA et al., 2018; MARINHO et al., 2019). Other alternatives include creating wells, tanks, and dams, which aim to facilitate the water access of part of the population.

Table 8 shows the annual analysis of SDEs, with each index's parameters, where it was possible to observe that for the indices, EW years only appear twice in the IAC, PNI, and DM indices. Then again, the ED years occur in two years in the RAI and DM and in three years in the PNI; it is evident that all the indices have distinct responses.

Another fact observed in Table 8 is that about 50% of the years in the different SDEs are between the dry and humid periods, configuring an equilibrium for the region in the study area. Thus, the important fact regarding the historical rainfall series, whether short or long, is the alternation between the rainy and dry cycles, which establishes a balance without canceling the intermediate activities (NASCIMENTO et al., 2019).

Furthermore, of the three SDEs analyzed in the study, the DM index had 24 similar data, or 67.85% of the other indices, while the RAI had 30 similar data with almost 100%, and the PNI presented 31 similar data, that is, 100% of the data correlated with the other SDE, reinforcing its importance in the proposed study.

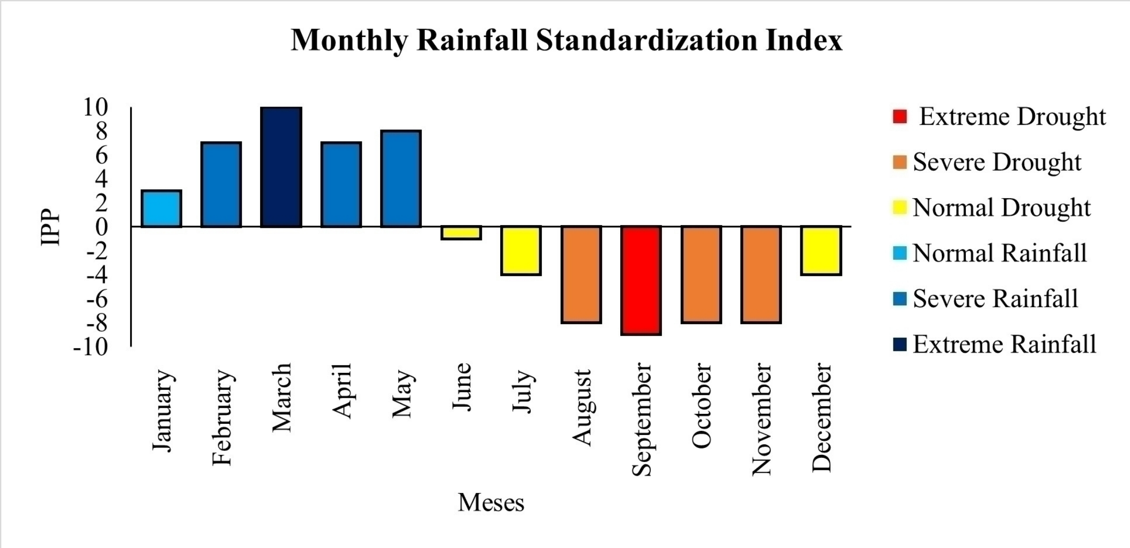

Figure 3 - REGIM's monthly Rainfall Standardization Index according to the new proposed classification. Prepared by the authors.

Hence, the RAI and PNI offer the best results in the study area, with close answers in both indices. The DM is also essential for research in both monthly and annual scales.

Year	Severity of events					
	IAC		DM		PNI	
1990	1.4	W	1.18	W	8	VW
1991	1.1	W	1.14	W	7	W
1992	2.9	VW	1.36	VW	9	VW
1993	-0.4	D	0,97	D	5	D
1994	0.3	W	1.03	W	6	W
1995	1.1	W	1.14	W	7	W
1996	-0.6	D	0,93	D	5	D
1997	-0.8	D	0.90	D	4	D
1998	-5.4	ED	0.32	ED	1	ED
1999	-3.5	VD	0.56	VD	1	ED
2000	1.4	W	1.17	W	8	VW
2001	-1.8	D	0.77	D	3	VD
2002	0.4	W	1.05	W	6	W
2003	-2.4	VD	0.71	VD	2	VD
2004	2.9	VW	1.37	VU	9	VU
2005	0.4	U	1.05	U	6	U
2006	1.2	U	1.14	U	7	U
2007	-0.4	D	0.95	D	5	D
2008	3.1	VU	1.39	VU	9	VU
2009	6.8	VE	1.85	VE	10	VE
2010	3.1	VU	1.39	VU	10	VE
2011	2.5	VU	1.32	VU	8	VU
2012	-5.7	ED	0.29	ED	1	ED
2013	-1.8	D	0.77	D	3	VD
2014	-1.2	D	0.85	D	4	D
2015	-3.3	VD	0.59	VD	2	VD
2016	-2.9	VD	0.64	VD	2	VD
2017	-2.0	D	0.75	VD	3	VD
2018	-0.6	D	0,93	D	5	D
2019	-0.7	D	0.91	D	4	D
2020	4.7	VW	1.59	VW	10	VW

Table 8 - Annual classification of SDEs on the scale from 1990 to 2020, according to the proposed new classification. ED = Extremely dry; VD = Very dry; D = Dry; W = Wet; VW = Very wet; EW = Extremely wet. Prepared by the authors.

The same procedure for the standardization of data in the monthly analysis was repeated for the annual analysis to understand better the proposed annual research of the flood or drought periods in REGIM, as shown in Figure 4. This shows that, on the whole, for the years in question, the annual IPP analysis corresponds to the proposed classification.

Therefore, according to the proposed SDE, as shown in Table 3, the study area has all possible variations. Fifteen years are classified as NR (1990, 1991, 1994, 1995, 2000, and 2002), SR (1992, 2004, 2008, 2010, and 2011) and ER (2009 and 2020). On the other hand, there were 16 dry years, classified into ND (1992, 1996, 1997, 2001, 2007, 2013, 2014, 2018, and 2019), SD (1999, 2003, 2015, 2016, and 2017), and ED (1998 and 2012).

When comparing the monthly and annual scales, it is evident that the latter has a more significant variation for the study area. A correlation between the years classified as ND or NR obtains a sum of 17 years or 55.2%.

These are classified as stable and with little significant impact. The years classified as SR or SD account for 10 years, or 33.2%, while only 4 years have ED or ER, with 11.6%. Nevertheless, it is these years that require the greatest attention.

The delimitation of SR years indicates periods of profound social, territorial, and environmental impacts. Voluminous rainfall causes difficulties in large urban centers through floods, risks of catastrophe, loss of cultivation, and harm to well-being, which are caused by poor management of water resources or lack of information from the periods analyzed.

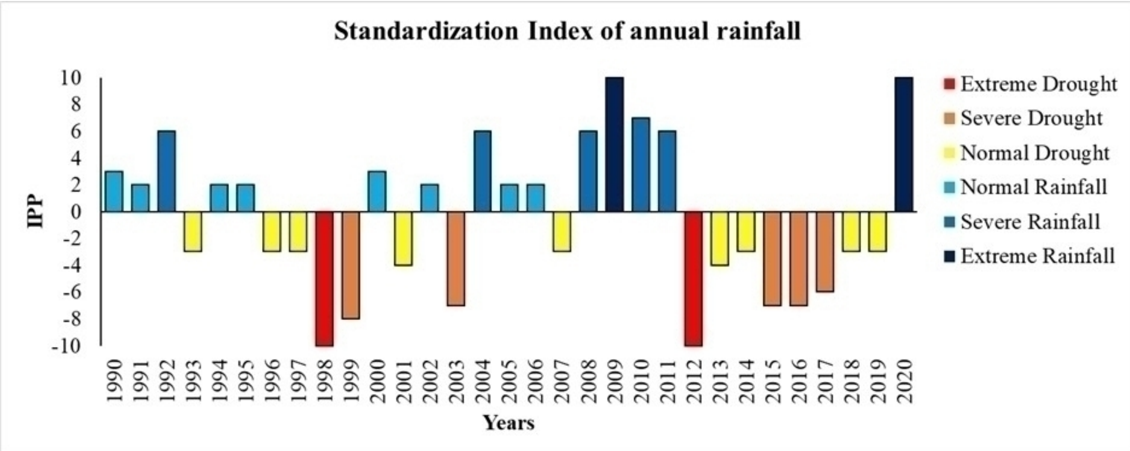

Figure 4 - Standardization Index of REGIM's annual rainfall, according to the new proposed classification. Prepared by the authors.

However, SDs have negative impacts beyond agriculture, bringing consequences from elevated temperatures, damage to human health, mortality of some species, rural exodus, and forced migration to other regions.

The years classified as ED or ER had severe impacts, especially those with the most intense drought index. 1998 and 2012 are similar and classified as "extremes" of drought. 1998 was followed by years of drought, unlike 2012, which had previous years classified as CS and CE, but subsequently had years of drought in the region until 2019.

Thus, Silva et al. (2018) state that the ED in these years caused temperature increases and a decrease in water resources, which affected the amount of water available in the region's reservoirs.

Similarly, to what happened in the dry period, the ER precipitation events occurred in two years, 2009 and 2020. 2008 was classified as a rainy year, and the region experienced intense rainfall until the end of 2011.

The year 2020 was preceded by eight years of drought. As a result, the ER this year provided water relief in the region, with an amount of rain that had not occurred for years, helping to increase water source levels, benefiting local agriculture, and improving the REGIM's water reserve.

The results for the REGIM contribute to municipal management, farmers' associations, and state and municipal environmental agencies, because knowledge of the periods highlighted at the annual and monthly level of insufficiency and/or rainfall extremes enable better water resources management and awareness raising of the population regarding the importance of rational water use, which is so essential in daily life.

Moreover, the results contribute to formulating public policies in REGIM that allow the construction of cisterns, sinking wells, and greater regulation of reservoirs.

In addition, they benefit and promote strategies for the coexistence of rural people to promote prosperous agriculture in the REGIM in both distinct periods, which will project future scenarios for improving water resource management.

Finally, geoprocessing tools can verify these scenarios through data collection of the chronological sequence of a given area, municipality, region, or state, making it possible to evaluate the water vulnerability of the REGIM's municipalities and project future scenarios.

Drought methods enable a positive or negative result for all the REGIM to be addressed. Notably, the set of these SDEs was fundamental in defining the parameters. Thus, the study of SDEs with the proposed new classification shows promising results that should be applied to other regions of the country.

CONCLUSION

REGIM - PB has two distinct precipitation periods, the rainy season, from January to May, and the dry season between June and December. SDEs are efficient in delimiting dry and rainy periods in the REGIM – providing the state with coexistence tactics. The RAI and PNI indices are noteworthy in the evaluation of rainfall extremes. The Monthly and Annual IPP were of great value to the REGIM, demonstrating the properties and determinations of each month and year. These results contribute to municipal and state governments, farmers, and state environmental agencies, preserving water resources in both periods of scarcity and abundance.Finally, they allow tactics for the coexistence of the rural people for the best coexistence in the REGIM periods, enabling the projection of future scenarios for water resource management.

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