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A NEW EVALUATION METHODOLOGY APPLICATION OF DRY SEVERITY FOR THE CITY OF CAMPINA GRANDE-PB

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Abstract

Droughts come from natural factors, and when they occur, cause changes in the climate, whether on a punctual or diffuse scale, and this cycle is constantly repeated, but in recent decades these impacts have increased with human actions from deforestation and burning of fossil fuels. Thus, the objective of this work is to employ a new application of the Drought Index methods (IAC, IPN and MD) to the data from the historical rainfall series of the municipality of Campina Grande - PB in the state of Paraíba, in order to classify the data on a monthly and annual scale, in order to identify the intensity over the years studied in this research. The pluviometric data used in the research correspond to the historical series from 1980 to 2019, which are divided into monthly precipitation data, provided by the Northeast Development Superintendence, National Institute of Meteorology and the Paraíba Water Management Executive Agency. The proposed methodology, in addition to the new standardization of the Drought Intensity Index (IIS), proposes a new characterization of the final rainfall condition or drought severity index. Finally, it allows environmental agencies and managers better conditions to adapt to problems related to drought and extreme rainfall, for greater management of water resources.

Keywords: drought intensity index, drought severity index, classes.

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Introduction

Droughts come from natural factors, and when they occur cause changes in the climate, been on a punctual or diffuse scale, and this cycle is constantly repeated, but in recent decades these impacts have increased with human actions from deforestation and burning of fossil fuels. Therefore, the impacts from droughts can destabilize the livelihoods of populations living in arid or semi-arid lands, which can lead to an invisible human development crisis and to the migration process (Unccd, 2014, Verner, 2016).

Thus, drought refers to the lack or reduction of rain over time in a given location, whose onset is difficult to detect. Furthermore, its impacts are multiple and severe, and may cause direct and indirect damages to environmental, economic, social determinants (Magalhães, 2016, Hagenlocher *et al.*, 2019, Meza *et al.*, 2019)

The knowledge of climatic characteristics and their projections are essential, as they show changes in precipitation and temperatures in the Northeast region (NEB), a fact that is closely associated with water availability and the conditions for adapting crops (Sales *et al.* 2015, Guimarães *et al.* 2016).

According to Costa and Silva (2017), the monitoring of droughts can be carried out by climatic indices, which characterize the dry and rainy time courses, to understand the behavior of rainfall, the climate variability of a location, state or region. Furthermore, with their knowledge, it is possible to know the severity of these phenomena and, consequently, their impacts.

Among so many climatic variables, rainfall is the one that has a positive or negative impact on society, since the most of the economic activities, especially agricultural, are affected in a long term by such variation, leading to a significant increase in extreme dry and rainy events (Costa *et al.*, 2015, Siqueira & Nery, 2017).

Therefore, drought is an anomaly that cannot be avoided and, therefore, it must always act in a preventive manner, in which there's the need for a better knowledge and interpretation of rainfall variability scales, which can be done through indexes (Alves *et al.*, 2016).

Droughts can be classified in distinct ways, among then, there's the Meteorological method, which is characterized by the lack of rain and the durability of dryness in a distinct environment, through a constant period of a month or more, during which the precipitation is below from the average rainfall values for the dry period (Noronha *et al.*, 2016). Therefore, hydrological drought is related to a deficiency in the volume of available water, including groundwater, reservoirs and rivers.

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In addition to the meteorological drought, it is also possible to highlight agricultural drought, caused by the lack of water in the soil for the plants development, which makes the water supply to crops inadequate to replace evapotranspiration losses (Duarte *et al.*, 2018).

Thus, it is possible to cite socioeconomic drought, which overtly links human production with agricultural production, which includes direct and indirect impacts on agricultural production and other kinds of economic activities (Fernandes *et al.* 2009).

The State of Paraíba is located in the NEB, and provides one of the greatest spatiotemporal rainfall variability, as the region of Cariri/Curimataú, that is the State's region that has a lowest rainfall ranging that is from 300 to 500 mm. In the Sertão and Alto Sertão the range is around 700 to 900 mm of rain. In the regions of Brejo and Agreste, rainfall ranging is from 700 to 1,200 mm, and the coast provides the highest average rainfall, which can exceed 1600 mm per year (Francisco *et al.*, 2015, Medeiros *et al.*, 2018).

This work applied different methodologies to determine drought indices for the city of Campina Grande-PB, such as the Decis Method (MD) - (Gibbs and Maher 1967), Rain Anomaly Index (IAC) - (Rooy 1965) which was readapted by Araújo *et al.* (2009) and the Normal Percentage Index (IPN) - (Cunha, 2008).

Thus, this work aims to employ a new application of the Drought Index methods (IAC, IPN and MD), to the data from the historical rainfall series from the city of Campina Grande in the state of Paraíba. As well as to classify the data as monthly and annual scale, in order to identify the intensity over the years studied in this research.

Material and methods

Study area

The study was carried out in the city of Campina Grande that is located in the State of Paraíba. The map was prepared in *QGIS software 3.10.12-A Coruña* (Figure 1), which comprises the former mesoregion of Agreste Paraibano and microregion of Campina Grande, today modified and changed by the new IBGE classification, it receives the name of Intermediate Region and Immediate Region of Campina Grande, being considered the second most influential city in the state.

So it is 112 km from João Pessoa, the state capital, covers an area of 591,658 km² of territorial extension and according to the IBGE (Brazilian Institute of Geography and Statistics), in 2020 its population was estimated at 411,807 inhabitants being the 2nd city of Paraíba in number of inhabitants. The city borders the NORTH with the cities of Lagoa Seca, Massaranduba, Pocinhos

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and Puxinanã, to the SOUTH with the cities of Boqueirão, Caturité, Fagundes and Queimadas, the EAST with the city of Riachão do Bacamarte and the WEST with the citiy of Boa Vista.

According to Alvares *et al.* (2014) the climate classification, as established by Köppen (1948), it is noted that the area is defined as tropical rainy, whose average air temperature in the coldest month exceeds 18ºC and the average annual precipitation is greater than 700 mm, with record of the least rainy season in spring-summer. For these conditions the climatic formula is determined as "As".

According to Cabral Júnior *et al.* (2018), the highest temperatures recorded in the city are from January to March, with an average of 24.5°C, and the lowest in July to August, with an average of 21.3°C. The average annual wind speed for Campina Grande is in the order of 4.11 m/s with the highest speed in September (~4.5 m/s) and the lowest speed in March (~3.4 m/s) (Santos, Silva, 2013).

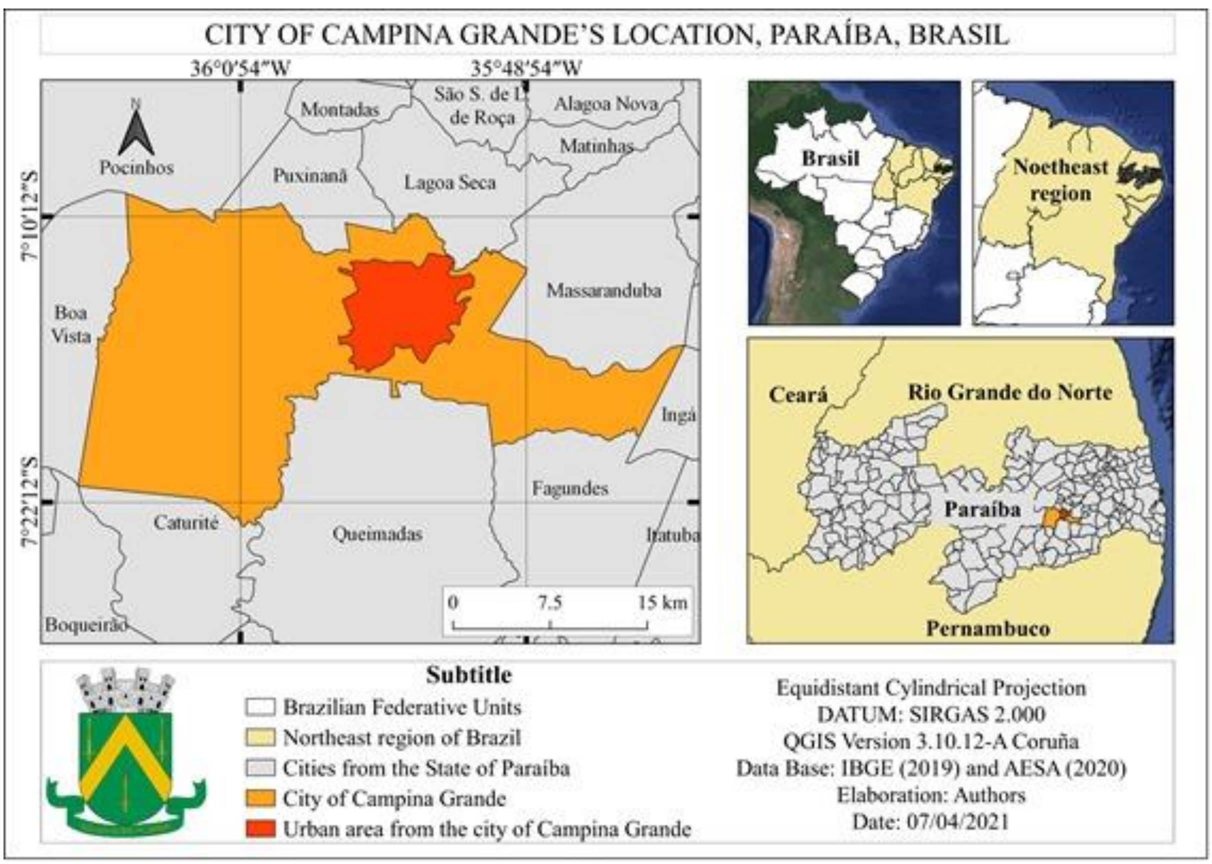

Figure 1. Location of the city of Campina Grande in relation to the State of Paraíba. *Source: By the authors.*

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Rainfall data

The rainfall data used in the research correspond to the historical series from 1980 to 2019, which are divided into monthly precipitation data, provided by the Superintendence for the Development of the Northeast (SUDENE), National Institute of Meteorology (INMET) and the Executive Agency for Water Management of Paraíba (AESA).

Through these temporal precipitation data, 3 meteorological stations were used and located within the studied municipality, making it possible to determine the monthly and annual rainfall, with the same values applied to the indexes under study.

It is noteworthy that the rainfall data showed failures in a few months within the rainfall stations. Therefore, statistical methods of regional weighting were used to fill the failures (filling failures) to complete the gaps and continue the research.

Statistical Modeling "Filling Failures"

The statistical method used to fill failures in the precipitation historical series was the regional weighting method according to Equation 1.

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

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

This method consists in estimating the rainfall that occurred with failure in the rainfall station, considering it adequate to the rainfall in neighboring stations, with the proportionality factor being the function of the average rainfall in these stations, taking into account the average rainfall station with failure. This method is employed by electing at least three neighboring stations with no data, which need to be located in climatic regions similar to the one with failure according to Table 1.

According to Table 1, it is noted that for the development of the research, other surrounding posts were needed, to fill the gaps in posts X, Y and Z, to determine the posts of Campina Grande José da Mata and Campina Grande Sitio Açude, since the one from Campina Grande EMBRAPA all data were complete.

After the filling failures procedure, the Dupla Massa method was applied (Figure 2) to prove the linearity of the predicted statistical model. Therefore, if the points of a given graph line up in an approximate straight line, this indicates a proportionality between the data of the two points in question.

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Table 1. Regional weighting method, applied to rainfall stations used in the research.

PX	PA	PB	PC
Rainfall Station Campina Grande São José da Mata	Rainfall Station Campina Grande EMBRAPA	Rainfall Station Puxinanã	Rainfall Station Montadas
Rainfall Station Campina Grande Sitio Açude	Rainfall Station Campina Grande EMBRAPA	Rainfall Station Campina Grande São José da Mata	Rainfall Station Boa vista
Rainfall Station Campina Grande EMBRAPA	##	##	##

It corresponds that the method was not applied.Source: By the authors.

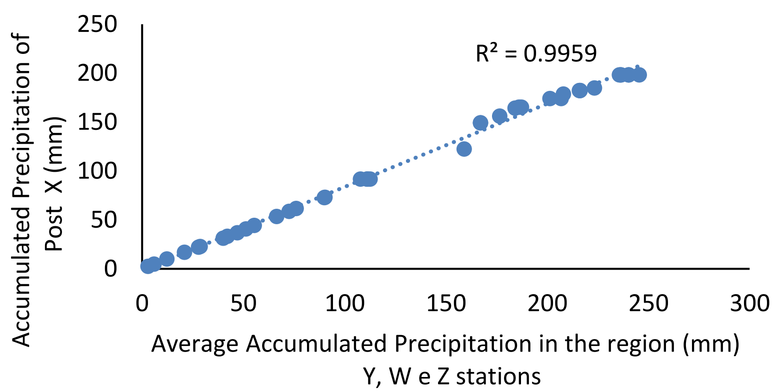

Figure 2. Exemple of Double Mass Analysis Model. *Source: By the authors*

Drought indices

After obtaining the historical series for each pluviometric station that is inserted in the city of Campina Grande-PB, the calculations for the three drought indexes were performed, with the aid of electronic spreadsheets in *Microsoft Excel 2016* for the organization of the precipitation series.

Method of Decis – MD

To calculate the MD, the means for each analyzed period were grouped in ascending order and, based on the accumulated frequency distribution, the series was divided into ten equal parts (deciles). Thus, this application was made using the R Studio 4.0.5 software, in which it was possible to verify the data in ten equal parts on the monthly and annual scale.

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The classification of this method was performed according to Gibbs and Maher (1967). Furthermore, it serves to determine the possibility of an event happening and also to qualitatively determine the climatic anomaly (Lima 2016).

Rain Anomaly Index – IAC

The IAC method has been used in several studies in recent years to define rainfall rainfall and the characteristics of a given region (Diniz *et al.* 2020, Nascimento *et al.* 2020, Nery & Siqueira *et al.* 2020).

Therefore, the analysis of the duration of the dry and wet periods was performed by calculating the IAC (Freitas, 2005), obtained from equations 2 and 3.

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

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

Being:
N = Current monthly precipitation (mm),
$\overline{N}$ = Average monthly precipitation of the historical series (mm),
$\overline{M}$ = Average of the ten highest monthly precipitations in the historical series (mm),
$\overline{X}$ = Average of the ten smallest monthly precipitations of the historical series (mm).

Normal Percentage Index – IPN

According to the NDMC (2020), the IPN provides simplicity in its calculations and can be used in different time scales, changing most of the time between a month or a set of months up to a year.

To calculate the IPN from Cunha (2008), on which express, as a percentage, the ratio between current precipitation and normal precipitation (average of 40 years) in a region, it was used the Equation 4.

$$IPN=\frac{P_{ATUAL}}{P_{NORMAL}} \qquad \textbf{Equação (4)}$$

On what,
IPN = Normal Percentage Index,
P_{ATUAL} = Precipitation at a given location (mm),
P_{NORMAL} = Average precipitation from the analyzed period (mm).

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New drought severity classification methodology and adaptations for MD, IPN & IAC indexes

It was considered that the analysis of the results of the various drought indices is difficult to understand, in this sense we tried to evaluate the degree of drought severity based on the classifications proposed for each of the evaluated indices. The use of classifications aimed to verify the frequency of different Drought Intensity Index (IIS) when applied in the city of Campina Grande-PB.

It is noteworthy that this procedure follows the time scale, suggested in the literature, which is over 30 years of data, to determine the intensity of droughts in a given region (Silva *et al.* 2020).

A new characterization of drought methods was used to standardize the IIS classification system for all applied methods MD, IAC and IPN, they are: extremely wet, very wet, wet, close to normal, dry, very dry and extremely dry.

On Table 2 shows the MD classification suggested by Gibbs and Maher (1967) and the classification proposed in the current work, in which different numerical intervals were adopted for each of the drought intensity classes. It is noted that the number of classes increased, to be in accordance to the method of all indexes proposed to be in a parameter for the same scale and properly identify the rainfall anomalies for the region.

Table 2. Relation between MD values and the one proposed by the authors.

Gibbs e Maher (1967)		Proposto	
MD	DRY INTENSITY	MD	DRY INTENSITY INDEX
10 – 9	Very Wet	10	Extremely Wet
8 – 7	Wet	9	Too Humid
6 – 5	Close to Normal	8 – 7	Wet
4 – 3	Dry	6 – 5	Close to Normal
2 – 1	Very Dry	4 – 3	Dry
		2	Very Dry
		1	Extremely Dry

Source: By the authors.

The Table 3 presents the classification of droughts suggested by Araújo *et al.* (2009) and the research proposal. Thus, following the IAC model in Table 3, a new class is added, that is Near Normal, and the quantification of values is remade to determine each parameter used, providing more subjectivity to the other IIS.

According to the model proposed for the IPN on Table 4, new Drought Intensities classes are added considering the wet values, in which there was an addition of three classes, remaining similar to the other IIS. Thus, this new proposition presents wet event values, which did not exist in Cunha's (2008) IPN.

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Table 3. Relation between values of IAC from Araújo *et al.* (2009) and the ones proposed by the authors.

Araújo *et al.* (2009)		Proposto	
MD	DRY INTENSITY	IAC	DRY INTENSITY INDEX
From 4 to above	Extremely Wet	From 5.1 to above	Extremely Wet
2 a 4	Too Humid	3.1 a 5	Too Humid
0 a 2	Wet	1.1 a 3	Wet
0 a -2	Dry	-1 a 1	Close to Normal
-2 a -4	Very Dry	-1.1 a -3	Dry
From -4 to bellow	Extremely Dry	-3.1 a -5	Very Dry
		From -5.1 to bellow	Extremely Dry

Source: By the authors.

Table 4. Relation between values from IPN from Cunha (2008) and the ones proposed by the authors.

Cunha (2008)		Proposto	
IPN	DRY INTENSITY	IPN	DRY INTENSITY INDEX
IPN ≥ 0.85	Normal	IPN ≥ 1,51	Extremely Wet
0.75 ≤ IPN < 0.85	Moderate Drought	1.31 ≤ IPN < 1.5	Too Humid
0.5 ≤ IPN < 0.75	Severe Drought	1.11 ≤ IPN <1.3	Wet
IPN < 0.5	Extreme Drought	0.91 ≤ IPN < 1.1	Close to Normal
		0.71 ≤ IPN < 0.9	Dry
		0.51 ≤ IPN < 0.7	Very Dry
		IPN < 0.5	Extremely Dry

Source: By the authors.

The proposed methodology, in addition to the new IIS standardization, proposes a new characterization of the final rainfall condition or drought severity index, they are: Extreme Rain (CE), Severe Rain (CG), Light Rain (CF), Normality (N), Low Drought (SF), Severe Drought (SG) and Extreme Drought (SE).

Classification of drought indexes in Campina Grande-PB on monthly and annual time scale

After analyzing the database and its classification in the two analyzed time scales (monthly and annual), Table 2 presents the final result of the proposed new methodology for identifying the drought intensity index – IIS.

Therefore, procedures were performed to transform this qualitative classification into a quantitative classification, in which the results of each IIS in a given year of the study period were analyzed according to the drought severity classification. According to this new approach, each index will receive a value according to the Drought Severity Index (ISS), BY the end these values will be added together, generating a "severity value".

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Table 5. Indexes Drought Intensity Classification MD, IAC e IPN.

Classification of the DROUGHT INTENSITY INDEX – IIS proposed	PROPOSED DROUGHT INDEXES		
	MD	IAC	IPN
Extremely Wet	10	From 5.1 to above	IPN ≥ 1,51
Too Humid	9	3.1 a 5	1.31 ≤ IPN < 1.5
Wet	8 - 7	1.1 a 3	1.11 ≤ IPN <1.3
Close to Normal	6 - 5	-1 a 1	0.91 ≤ IPN < 1.1
Dry	4 - 3	-1.1 a -3	0.71 ≤ IPN < 0.9
Very Dry	2	-3.1 a -5	0.51 ≤ IPN < 0.7
Extremely Dry	1	From -5.1 to bellow	IPN < 0.5

Source: By the authors.

As noted, the rating can range from “Extreme Drought” to “Extreme Rain” among the seven ISS. In this sense, such classification parameters will be applied in the monthly and annual scale, for a better understanding of the results.

In creating this new approach to drought classification, it was taken into account that all three methods have the same magnitude of the proposed drought IIS, as explained in Table 5. This global value was then used to determine the ISS of all the months and years from the time course adopted in the work.

Therefore, values were delimited for the IIS in which it was established based on the possible sums of intensity values and receiving the name of Drought Severity Index - ISS (Table 6) that can be observed some combinations of drought intensity classes and their rating.

The possible combinations of the IIS of the IPN, MD and IAC defined this classification of the ISS. In view of the possible scenarios that could present similar or different answers between them

After analyzing the data set, dividing it into seven classes as shown in Table 6, ranging from "Extreme Drought" to "Extreme Rain" as already presented, the result was a division of twenty-four drought severity values according to the ISS proposed for the three methods analyzed.

Thus, for each ISS value, a name was established in the proposition of the new classification approach, in which each class has its values determined precisely by the set of possible results presented by the IIS in Table 5. Therefore, the proposed ISS was divided into seven classes named Extreme Drought, Severe Drought, Light Drought, Normality, Light Rain, Severe Rain and Extreme Rain, which were further subdivided into their intensity values.

According to Table 6, the respective severity values were standardized as follows: The severity called Extreme Drought, which has severity 1 and 2, takes into account that, when there are three equal ES results in all indexes, for example, grade 1 will be awarded, whereas to receive grade 2, it is considered that two of the three indexes present ES and only one MS.

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Table 6. Conjecture of drought combinations' intensity classes to determine the Drought Severity Index score.

Drought Severity Index	Valor de Severidade	Métodos de Índices de Seca estudados		
		IPN	MD	IAC
Extreme dry	1	ES	ES	ES
	2	ES	ES	MS
Severe drought	3	ES	MS	MS
	4	MS	MS	MS
	5	MS	MS	S
	6	ES	MS	S
Weak drought	7	MS	S	S
	8	S	S	S
	9	S	S	PN
	10	MS	S	PN
Normality	11	S	PN	PN
	12	PN	PN	PN
	13	PN	PN	U
	14	S	PN	U
Light rain	15	PN	U	U
	16	U	U	U
	17	U	U	MU
	18	PN	U	MU
Severe rain	19	U	MU	MU
	20	MU	MU	MU
	21	MU	MU	EU
	22	U	MU	EU
Extreme rain	23	MU	EU	EU
	24	EU	EU	EU

ES = Extremely Dry, MS = Very Dry, S = Dry, Near Normal =PN, U = Wet, MU = Very Moist, EU = Extremely Wet.
Source: By the authors.

Then, Severe Dry severity was standardized into four values, ranging from 3 to 6, where it was possible to highlight the severity intensity of 3 when the indexes results presented two MS and one ES. As for the intensity of severity 4, all indices have MS. For the intensity of severity 5, it is taken into account that they have two MS and one S, and putting an end to the intensity of severity 6 is assigned when the indexes have variations of an ES, MS and S, in which case the intensity of rating severity to average condition.

The classification of the Dry Weak class takes into account the intensity ranging from 7 to 10, in which it is possible to notice that the class 7 is assigned when there are two S and one MS. Intensity 8 is when all indexes are presented with S. Furthermore, intensity 9 is when it has two S and one PN, and then intensity 10 is when the indexes have different values such as MS, S and PN.

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Posteriorly, the Classification of the Normality class takes into account the severities ranging from 11 to 14, in which it is possible to detect that class 11 is represented by one S and two PN. Severity 12 is represented with all three indexes as PN. For severity 13 there are two PN and one U, and putting an end to severity 14, the last of the normality class, refers to S, PN and U.

Regarding the Weak Rain class, which ranges from 15 to 18, severity 15 will occur when it has two U and one PN. As for 16, when all indices are U. Furthermore, severity 17 will be composed by two U and one MU, while severity 18 will be composed when PN, U and MU appear between them.

The penultimate class is Severe Rain, in which it has four severities ranging from 19 to 22, in which severity 19 is composed when two indexes present as MU and a U. Already 20 when all indexes present as MU. Severity 21 when there are two MU and one EU, and severity 22 when the variables U, MU and EM appear in different indexes.

Finally, the last class called Extreme Rain, which has two severities, 23, which will be used when two EU and one MU occur, and 24 when all severities are presented as EU.

Therefore, when applying the drought classification system in the proposed monthly and annual time scale, it sought to verify the frequency of the most extreme anomalies and a possible pattern existing in the time series.

Then, the classification system will allow examining the drought conditions and thus identifying the months and years with the most extreme ISS, being those of "Extreme Rain or Extreme Drought", and observe their relationship in the chronological sequence of the study, verifying its variations.

Results and discussion

By analyzing the pluviogram (Figure 3), it is possible to observe two distinct seasons, a period of six rainy months and another with six dry months. Moreover, the data obtained, it was verified that the rainy season occurred between the months of February to July, with the month of June being the month with the highest precipitation measure, in which it reached an average precipitation of 97 mm. In contrast, the dry season occurs between the months of August to January, with November as the driest month with 7.2 mm.

For Almeida and Cabral Júnior (2014), in this location, autumn and winter are wetter and, on the other hand, spring is the driest season, accumulating less than 10% of the total precipitation annually.

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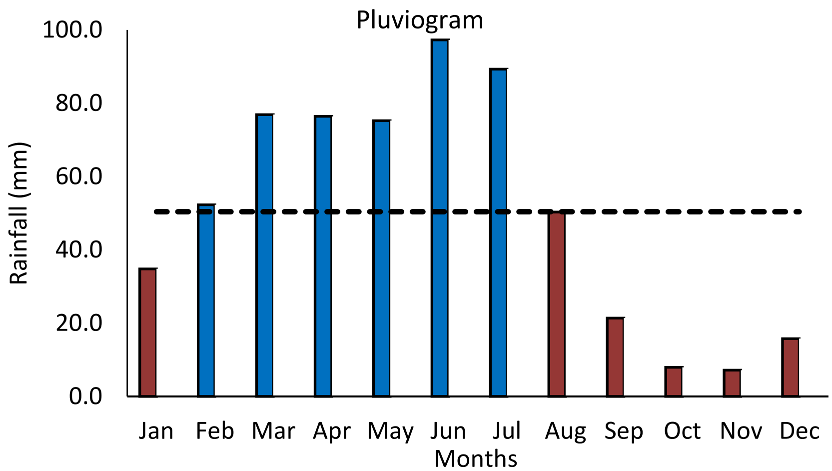

Figure 3. Monthly Precipitation Pluviogram from the 40 Years of Campina Grande City. *Source: By the authors.*

The results from the IPN, MD and IAC methods are presented in two different time scales (monthly and annual) for the city of Campina Grande-PB. Therefore, according to Table 7, the MD presented a higher correlation with the three methods, obtaining similar results in six months for both the IPN and the IAC, in this sense they are the indexes of greater constancy and veracity for this area because their results are closer.

On the other hand, the IAC and the IPN, if compared between them, present a diversity between their results, obtaining only two similar months, when comparing the IAC with the MD, six results are identical, and the other six similarly between the IPN and the MD, with six months with identical results, and six months with different results. Therefore, it appears that the MD is the most suitable for the monthly analysis, as it reaches its reality, while the IPN and the IAC corroborate with the MD, in similar results, further reinforcing the characteristic of each index.

According to Table 7, it can be seen that each month had its particularity in the different drought severity indexes, highlighting its proximity between one or more ISS, following approximately the same class, thus showing a sign of severity in the information linked to the region, in which it was possible to delimit the monthly ISS.

It is possible to verify that the period of the studied historical series had 10 rainy years, 12 normal, and 18 dry years (Figure 4), years varying between rainy and dry months, delimited according to the new proposed scale, where the months of February stand out. In addition, August considered as transition months between the wettest and the driest period, as they were characterized as normal months.

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Table 7. Monthly classification of ISS on the scale from 1980 to 2019 according to the new proposed classification.

Indexes	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IAC	-1.3	0.1	2.2	2.2	2.1	4.1	3.5	0	-2.3	-3.4	-3.5	-2.8
	S	PN	U	U	U	MU	MU	PN	S	MS	MS	S
IPN	0.69	1.04	1.53	1.52	1.49	1.93	1.77	1	0.42	0.16	0.14	0.31
	MS	PN	EU	EU	MU	EU	EU	PN	ES	ES	ES	ES
MD	4	6	9	8	7	10	10	5	3	1	1	2
	S	PN	MU	U	U	EU	EU	PN	S	ES	ES	MS

ES = Extremely Dry, MS = Very Dry, S = Dry, PN = Near Normal, U = Wet, MU = Very Moist, EU = Extremely Wet. *Source: By the authors.*

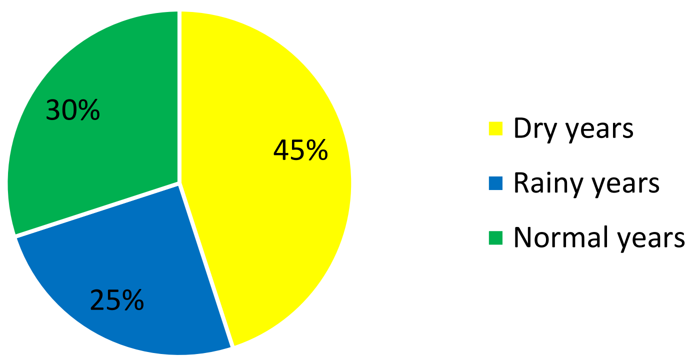

Figure 4. Historical series Percentage from 1980 to 2019, according to the ISS. *Source: By the authors.*

Through the used methods and the classification proposed for the ISS, which used the average monthly data from 1980 to 2019 that the studied area presented two distinct periods (Figure 5). The rainy season having its maximum precipitation between March and July and the dry precipitation in the months of September to January, thus demonstrating the months with the highest (June and July) and lowest rainfall contribution and consequently the months with the greatest water shortage (October and November), these months have low water, which is the time of year when it rains less regularly in the city and represent similar results with temporal rainfall in Figure 3.

Therefore, fresh water in perfect conditions, found on planet, has been increasingly appreciated by society in general, in such a way by the popularity of aquatic ecosystems conservation, and its availability is a determining factor for human well-being, thus as for several other managements (Glória, 2017, Oliveira *et al.*, 2017, Meschede *et al.*, 2018, Calado *et al.* 2020).

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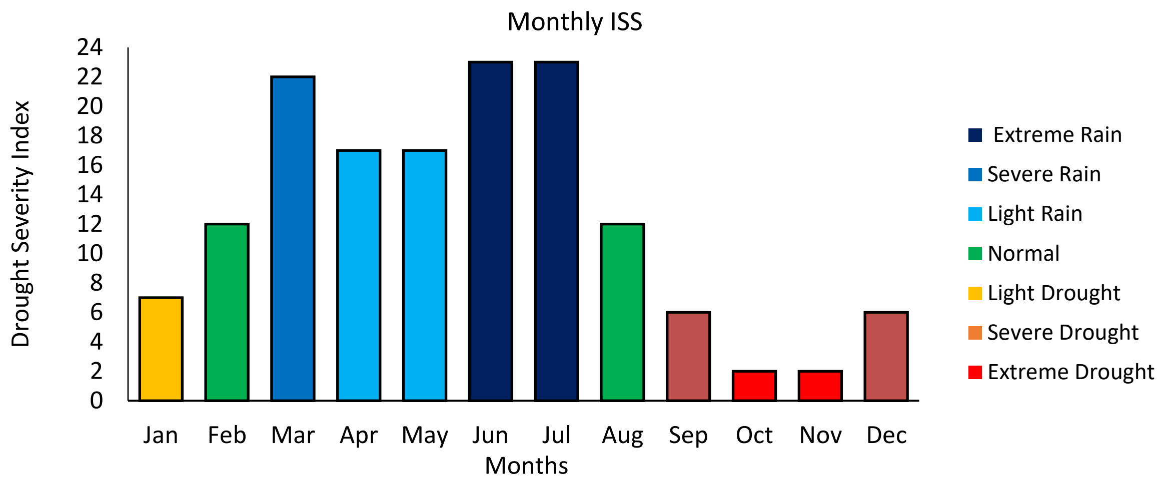

Figure 5. Monthly Drought Severity Index for the city of Campina Grande-PB according to the new proposed classification. *Source: By the authors.*

Therefore, in Brazil, it was observed that the lowest water quality is found on metropolitan areas and in some reservoirs in the Semiarid region when compared to other regions of the country (Ana, 2019). Furthermore, it is necessary to manage local water resources based on information on time course of greater and lesser water contribution in the studied area.

By this way, they aim at policies that prioritize water conservation in periods of scarcity and periods of more abundant use of water sources during the wet period, as well as the encouragement of agricultural activities peculiar to the city, thus benefiting the constancy of man in the countryside and socioeconomic development.

Therefore, these results contribute to the city planning of water resources, to reduce the impacts on the quality of water in rivers and lakes and, consequently, to public health and balance of ecosystems (Rosa *et al.*, 2016). In addition, emphasize the importance of agricultural activities, and production control practices, in addition to helping to identify climate weaknesses in the city and region.

The Table 8 presents the annual analysis of the ISS, in which each index presented different results, where it was possible to observe that, for the three indexes with positive extreme years they appear in three years in a similar way (2000, 2004 and 2011) and in the MD it also appears in 1984 where it is possible to observe that for all indexes the condition of years classified as extreme wet were significant in all indexes.

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Table 8. Annual classification of ISS on scale from 1980 to 2019 according to the new proposed classification.

Year	Drought Indexes					
	IAC		IPN		MD	
1980	-0.7	PN	0.94	PN	6	PN
1981	-0.4	PN	0.96	PN	6	PN
1982	-1.9	S	0.82	S	3	S
1983	-0.6	PN	0.94	PN	6	PN
1984	3.8	MU	1.45	MU	10	EU
1985	2.7	U	1.32	MU	9	MU
1986	-1.2	S	0.89	S	4	S
1987	0.4	PN	1.04	PN	8	U
1988	-0.4	PN	0.97	PN	7	U
1989	-4.6	MS	0.57	MS	1	ES
1990	-3.7	MS	0.65	MS	1	ES
1991	-1.3	S	0.88	S	4	S
1992	1.8	U	1.22	U	8	U
1993	-1.1	S	0.9	S	5	PN
1994	2.9	U	1.35	MU	9	MU
1995	-2.4	S	0.77	S	3	S
1996	-0.7	PN	0.93	PN	6	PN
1997	-2.5	S	0.76	S	3	S
1998	-5.9	ES	0.44	ES	1	ES
1999	-3.1	MS	0.7	MS	2	MS
2000	7.3	EU	1.87	EU	10	EU
2001	0.1	PN	1.01	PN	7	U
2002	0.3	PN	1.04	PN	8	U
2003	-1.4	S	0.87	S	4	S
2004	6.1	EU	1.73	EU	10	EU
2005	1.5	U	1.17	U	8	U
2006	-1.6	S	0.85	S	3	S
2007	0	PN	1.01	PN	7	U
2008	1.9	U	1.23	U	9	MU
2009	2.7	U	1.32	MU	9	MU
2010	0.3	PN	1.04	PN	8	U
2011	7.4	EU	1.89	EU	10	EU
2012	-2.8	S	0.74	S	2	MS
2013	-0.7	PN	0.93	PN	6	PN
2014	-0.9	PN	0.91	PN	5	PN
2015	-3.3	MS	0.68	MS	1	ES
2016	-2.9	S	0.69	MS	1	ES
2017	-2.9	S	0.73	S	2	MS
2018	-1.2	S	0.89	S	5	PN
2019	-1.2	S	0.89	S	5	PN

ES = Extremely Dry, MS = Very Dry, S = Dry, PN = Near Normal, U = Wet, MU = Very Moist, EU = Extremely Wet. Source: By the authors.

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On the other hand, the years classified as extreme or negative Drought were presented in the indexes in agreement in the year of 1998, in addition, in the MD in the years of 2015 and 2016. The results found as "close to normal", appear in the IAC and IPN in 11 years, and in the MD in 9 years, with some similar results in both (1980, 1981, 1983, 1996, 2013 and 2014) and in others through of its indexes with distinct characteristics. Thus, the number of years in the use of the three indexes on the annual scale showed that the most commonly found values are precisely those close to normal, corroborating with Nascimento *et al.* (2019) who states that in short or long series of precipitation, the main thing is the alternation between the dry and rainy cycles, since this will understand a balance without damaging the activities on the environment.

According to Table 8, among the three drought methods analyzed in the study, MD presented 23 similar data, being the least remarkable index, while the IAC presented 36 similar data, almost all of the analyzed years and finally the IPN presented 39 data similar compared to other IIS, being basically efficient at 99% of results on the annual scale, making it the most regular index.

Therefore, the IPN stands out among the results in the studied city, but the other IIS also had positive responses, such as the IAC, which obtained about 90% with data similar to the other indexes, and the MD, which was the index with the highest representation through monthly analysis.

Therefore, with the use of IIS (MD, IPN and IAC) it is possible to reach a positive or negative result for the municipality, highlighting that the set of indices was extremely important to delimit the parameters. Thus, the study of indices with the new ISS classification showed promising results that can be applied to other cities, regions and states.

By the same way that they were used to standardize the monthly study, the annual analysis was also proposed in order to better understand the proposed annual study, of the periods of flood or drought in the city of Campina Grande-PB, as shown in Figure 6, which demonstrates the annual analysis, according to the classification proposed by the ISS.

Therefore, the study area has, according to the new classification proposed by the ISS in Table 8, all possible variations, presenting 18 dry years classified as EXTREME DRY (1998), SERIOUS DRY (1989, 1990, 1999, 2015 and 2016) and WEAK DRY (1982, 1986, 1991, 1993, 1995, 1997, 2003, 2006, 2012, 2017, 2018 and 2019).

On the other hand, the studied area had 10 rainy years, being classified as LITTLE RAIN (1992, 2005 and 2008), SERIOUS RAIN (1984, 1985, 1994 and 2009) and EXTREME RAIN (2000, 2004 and 2011). In addition, according to the ISS classification, the municipality also presented 12 years classified within its NORMALITY, which were the years (1980, 1981, 1983, 1987, 1988, 1996, 2001, 2002, 2007, 2010, 2013 and 2014).

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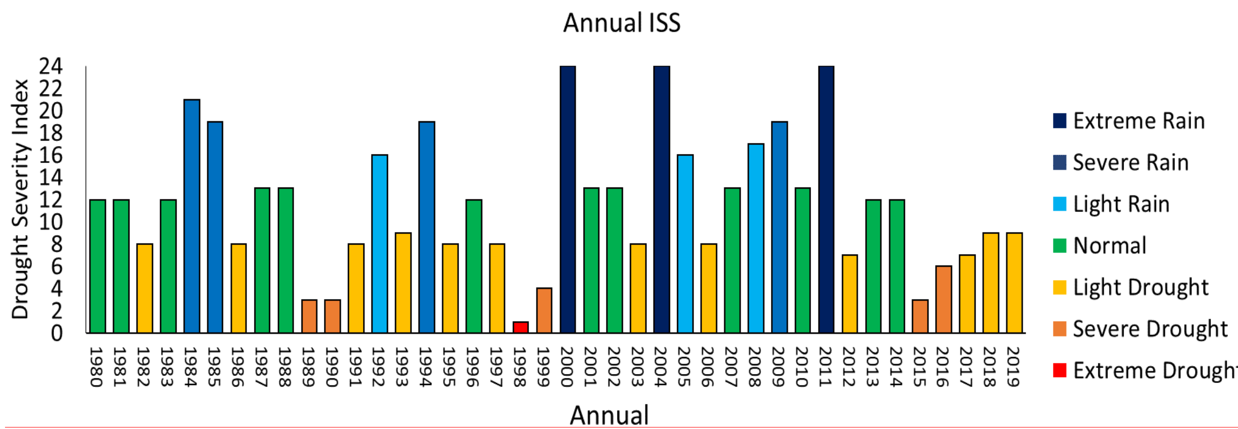

Figura 6. Annual Drought Severity Index for the city of Campina Grande-PB according to the new proposed classification. *Source: By the authors.*

Therefore, through these results, it is observed within the monthly and annual scales that the annual scale has a greater variation for the area under study. If a call is made between the years classified as Normal, which represents 12 years or 30%. In addition, if comparing the rainy and dry periods, the distance in relation to the dry period (18 years or 45%) according to figure 4 on the rainy period (10 years or 25%) is greater with a result of 8 years.

Thus, further breaking down each result, in the dry periods we can characterize that according to Figure 6, about 12 of the 18 years of the analyzed period and which was characterized as dry, droughts are characterized as weak, and severe droughts were represented in 5 years, and extreme drought in just 1 year.

On the other hand, the rainy period, which had 10 years, was divided into 3 years for light rain, 4 years for severe rain and 3 years for extreme rain. In this sense, it is noted that despite the few years of rain compared to the dry period, but the largest proportion occurred in periods of extreme and severe rain with 7 representations.

With this delimitation between the years of "Extreme Rains and Droughts", periods of great impacts, both economic, social and environmental, stand out, in a perspective that excessive rains bring with them problems in large urban centers such as floods, risks of environmental disasters, loss of crops and damage to health, if there is no adequate management of water resources or lack of knowledge of the periods under analysis. Therefore, Seluchi *et al.*, (2016) states that floods from rains are caused by disorderly population growth and by changes in land use and local climate changes.

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On the other hand, extreme droughts cause, in addition to low productivity in agriculture, an increase in temperature, damage to human health, animal mortality, among others. We still can cite droughts directly affect the reduction of cattle, goats and sheep herds (Farias & Sousa, 2020).

In addition, the years that had extremes were years that came from a year before of drought or normality, for the rainy season, and when the extreme was negative, it was because the year before it also had been from a drought.

For the years classified as "Severe Rain or Dry", which represent 9 years, 4 rainy and 5 dry, it is noted that in almost all results both occurred after years of normality, or before the same with the exception of only from the years 1999, which came with an extreme drought before, and 2009 which saw a significant increase in rainfall from 2008 to 2009.

The years classified as "Weak Rain or Dry" had about 15 years analyzed, and are close to normality, with some distinct characteristics and factors, it was noted that out of the 15 years, 12 were dry and 3 were rainy. This characterizes that the region suffered from lighter droughts and less significant rains, which dynamizes in the previous results that higher rains provided support for the region in the years shown.

For the years that were presented as “Normality”, they showed that the rains or droughts in the region in those years did not directly affect human activities, nor the relationship with nature, nor did it cause problems for local agriculture and livestock.

By this way, the results achieved, cooperate for the local manager, farmers and State environmental agencies, extensive information on the periods of greatest shortage and maximum abundance of water resources. In order to accept conjectures of public policies that authorize tactics for the coexistence of man from the countryside and inland for a better coexistence at both different times and from this configuration will project future scenarios for the management of water and environmental resources in the city.

Finally, these scenarios can and should be prevented through geoprocessing, through data collection of the time series of a given area, place or region, which allows us to see the issue of vulnerability in which a location is found and to prospect later panoramas. In addition to this means, there are other methods, through computational, mathematical and statistical models.

Conclusions

The city of Campina Grande-PB has two distinct periods of rain, a rainy one between February and July, and a dry one between August and January.

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The use of IIS methods is efficient in the delimitation of dry and rainy periods in the city of Campina Grande-PB. Thus, highlighting the MD method in the monthly analysis and the IPN method in the annual analysis in the evaluation of the extremes of the place.

The Monthly and Annual ISS were of great support for the municipality studied, in which it showed characteristics and delimitations of each month and year, contributing with significant information for each month and year analyzed.

The IIS help in the development of the ISS, being a fundamental point for the new proposed methodology, thus helping and highlighting the present indices.

The proposed new methodology makes easier to understand the results, so that the ISS helps to understand the behavior of drought or rain events over the months and years.

Finally, it allows environmental agencies and managers better conditions to adapt to problems related to drought and extreme rainfall, for a better management of water resources.

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