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Development of an annual drought classification system based on drought severity indexes

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Abstract: In order to characterize the occurrence and intensity of droughts in the Doce River Basin, as well as to develop a system for its classification, four different drought indexes were evaluated: Percent of Normal Precipitation (PNP), Deciles Method (DM), Rainfall Anomaly Index (RAI) and Standardized Precipitation Index (SPI). The indices were calculated annually, based on precipitation data from 89 rainfall stations of the Brazilian National Water Agency (ANA). Nine analysis units (AUs) were determined in the basin and the Thiessen Polygons method was used to obtain the average precipitation in the respective drainage areas. The indices were calculated for each AU and then related to the drought intensity classes. An overall classification of the indices was proposed for the drought classification system for a 30-year base period, from 1985 to 2015. The most critical hydrological years of the Doce River Basin in relation to the drought were 1994/1995, 2000/2001 and 2014/2015, the latter being the most critical of the last 30 years. The results show that the annual drought classification system proved to be efficient in the identification of events, allowing to verify that the Doce River Basin presents a severe climatic drought condition, on average, every seven years.

Key words: climatic condition, Doce river, precipitation, rainfall season, river basin.

INTRODUCTION

Drought is defined by Hayes et al. (2011) as the precipitation deficit in relation to the historical averages of a given region. While some disasters such as floods, earthquakes and hurricanes are restricted to structural damage and have sudden beginning and end, the drought, according to Byun and Wilhite (1999), is a temporary situation with duration, magnitude, and severity, that spreads through large geographic area, almost always with slow beginning and extensive duration (Mishra and Singh 2010).

Because it is a natural, recurrent and complex event, attempts are made to predict its beginning, end, and severity. This process involves the

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calculation of drought indices, which incorporate hydrometeorological data that provide information on historical droughts to monitor current conditions (Santos et al. 2013).

Fernandes et al. (2010) state that drought rates are, however, important for adopting different indices for a performance assessment. Among the various indexes, the most important are: Percent of Normal Precipitation - PNP, Deciles Method - DM (Gibbs and Maher 1967), Rainfall Anomaly Index - RAI (Rooy 1965) and Standardized Precipitation Index - SPI (McKee et al. 1993).

The application of drought indexes in different study areas throughout the Brazilian territory is very common. It is worth mentioning the large number of studies focused on the northeast region (Oliveira Júnior et al. 2012, Macedo et al. 2010), due to the predominance of semiarid climate, marked by low volumetric precipitation and prolonged drought.

In this context, it is intended to evaluate four different quantitative indices (PNP, DM, RAI and SPI) to characterize the intensity and occurrence of droughts in the Doce River Basin and to develop a drought classification system capable of identifying the most critical years in the basin, as well as the regions that suffer most from the consequences of this climatic anomaly.

MATERIALS AND METHODS

The Doce River Basin is located in the southeast region of Brazil, between the parallels 17º45' and 21º15' S and the meridians 39º30' and 43º45' W. Most of the 86,710 km^2 of its area is comprised in the State of Minas Gerais (86% of the area) and the rest in the State of Espírito Santo, including 230 municipalities in total (PIRH DOCE 2010).

In order to conduct the study in a more organized and efficient way, the basin was divided into 9 analysis units (AU), 6 of them in Minas Gerais and 3 of them in Espírito Santo, according to Figure 1.

In order to calculate the PNP, DM, RAI and SPI indexes, monthly rainfall series from pluviometric stations belonging to the ANA hydrometeorological network, located in and around the Doce River Basin, were used.

First, 165 stations were selected for analysis taking into account the existence of a minimum of 30 continuous years of monthly precipitation data, the availability of recent data and the existence of few gaps in the historical record (up to a maximum of 5% of failures). At the end of this evaluation, 89 that fit within the established requirements stations were selected, which are highlighted in Figure 1.

The same baseline period from 1985 to 2015 was adopted for all 89 pluviometric stations, satisfying the criterion of using at least 30 years of data. It should be noted that, according to Marques (2010), the hydrological year adopted in the Doce River Basin begins in October and ends in September, and for that reason, the beginning of the baseline period was adopted in October 1985 and the end in September 2015 (360 months).

The pluviometric stations monthly data were only consisted up to the year 2005. However, it was also decided to work with the raw data from 2006 to 2015, since these are recent records. In order to avoid inconsistencies in the analyzes, the whole database was checked, in order to identify gross errors caused by equipment failures or mistaken typing of rain gauges.

The simple linear regression method was used to fill gaps in the precipitation monthly data series, as recommended by Pruski et al. (2004). In order to select the support stations used to fill in the gaps, only those that had data in the same period to be filled in the station with errors in their records were adopted. In addition, a coefficient of determination (R^2) greater or equal to 0.70 was adopted in order to guarantee greater reliability to the methodology.

To evaluate the drought in the entire study area, the mean monthly precipitation for each of the AUs was used, which was obtained by spatialization

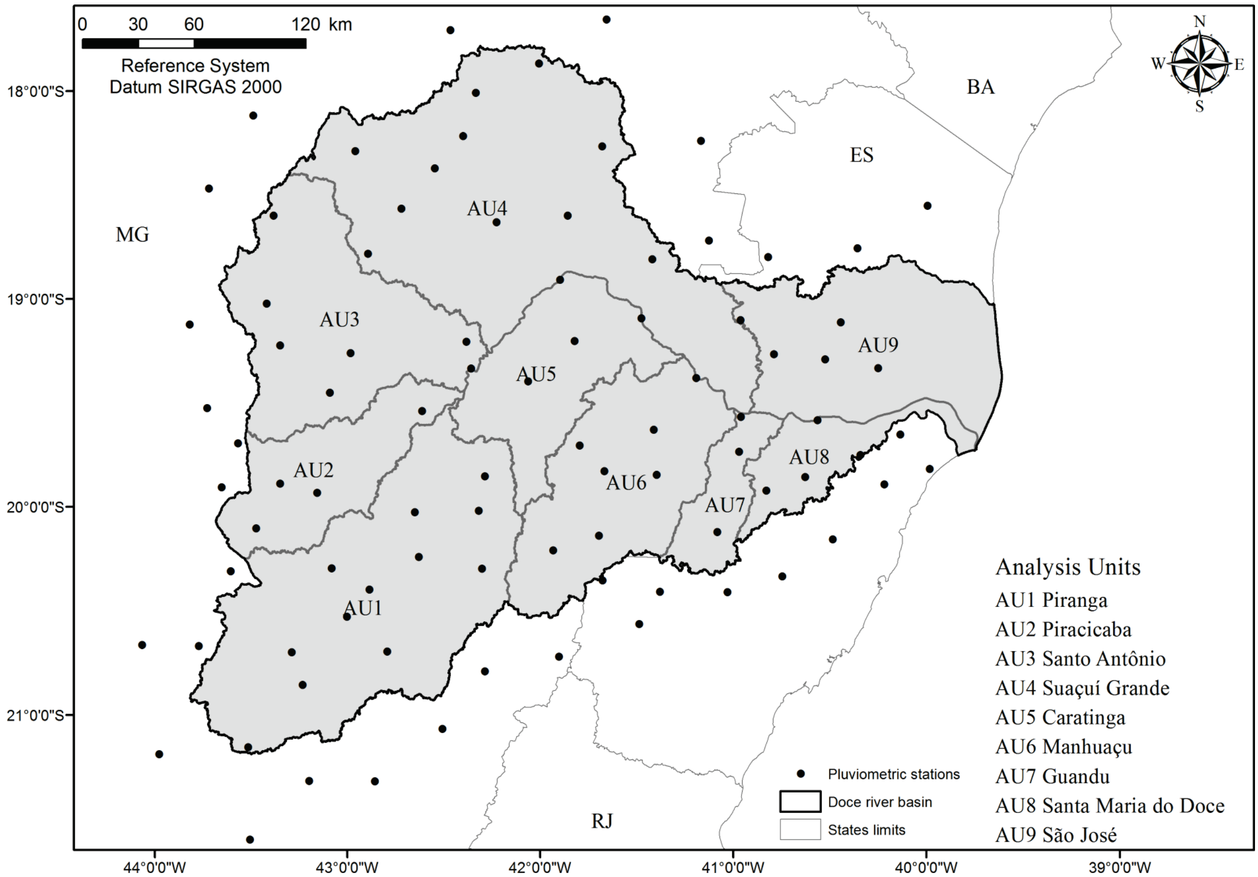

Figure 1 - Analysis units (AUs) and pluviometric stations of the ANA hydrometeorological network selected for the study in the Doce River Basin.

of the rainfall records according to the Thiessen polygons method (Thiessen 1911). The historical series were obtained for each of the nine AUs and the calculations of the four drought indices were performed on the annual scale.

For the estimation of PNP, which expresses, in percentage, the ratio between the actual precipitation and the normal precipitation (average of 30 years) of a region, Eq. 1 was used.

$$PNP = \frac{P_{actual}}{P_{normal}} \quad (1)$$

where:

P_{actual} - precipitation at a given location on the time scale adopted (mm); and

P_{normal} - average precipitation of the site for the period from 1985 to 2015 (mm).

For the calculation of the DM, the precipitation values in deciles (tenths of the data distribution) were grouped, dividing the series into ten equal parts, from the lowest precipitation to the highest precipitation, in order to generate a cumulative frequency distribution. Subsequently, the deciles were classified according to Gibbs and Maher (1967), as presented in Table I.

The RAI calculation was performed using Eq. 2. The positive anomalies, with values above the historical mean of precipitations, were calculated with a positive sign whereas, the negative anomalies related to the periods of rainfall deficit, were calculated with the negative sign.

$$RAI = \pm 3\left[\frac{(p-\bar{p})}{(\bar{x}-\bar{p})}\right] \quad (2)$$

where:
p - actual precipitation (mm);
$\bar{p}$ - average precipitation of the site for the period x from 1985 to 2015 (mm); and
$\bar{x}$ - average of the ten largest or the ten smallest precipitations (mm).

In order to obtain the SPI, the first step was the adjustment of the precipitation data series to the Gamma probabilistic distribution, as recommended by Blain et al. (2010), since it adequately describes the behavior of the rain, in a flexible way, involving only two parameters (form and scale), which were estimated for each AU and for each month of the year. After adjustment to the Gamma distribution, the data was fitted to the cumulative probability distribution. Finally, the cumulative distribution was transformed into a normalized random variable (Z), with mean zero and standard deviation equal to unity, which corresponds to the SPI value (Eqs. 3 and 4, supported in Eqs. 5 and 6).

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \text{ for } 0 < H(x) \leq 0.5 \quad (3)$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \text{ for } 0.5 < H(x) \leq 1 \quad (4)$$

where:

$$t = \sqrt{\ln\left[\frac{1}{(H(x))^2}\right]} \text{ for } 0 < H(x) \leq 0.5 \quad (5)$$

$$t = \sqrt{\ln\left[\frac{1}{1-(H(x))^2}\right]} \text{ for } 0.5 < H(x) \leq 1 \quad (6)$$

c_0 - 2.515517; c_1 - 0.802853; c_2 - 0.010328;

d_1 - 1.432788; d_2 - 0.189269; d_3 - 0.001308.

Since the analysis of the numerical results of the various drought indexes is often difficult to understand, the degree of drought severity was evaluated based on the proposed classifications for each of the indices evaluated (Table I).

In the present study, the four indices were adapted to their classes and classification intervals by means of a standardization in the classification system in four dry intensities: normal (N), moderate drought (MD), severe drought (SD) and extreme drought (ED). The numerical intervals of the classes were modified in order to adjust the utilization of the indexes in the study region, since most of these indexes were developed for semi-arid regions, with annual mean rainfall below 500 mm, rainfall much lower than the average 1,175.2 mm of the Doce River Basin (Table IV).

Thus, after the standardization, a global classification was created to evaluate the drought phenomenon in the 9 AUs of the Doce River Basin, as presented in Table II.

The results of each index were analyzed according to the classification of drought severity in each year of the base period, in order to transform this qualitative classification into a quantitative classification. In other words, a given index received the grades 0, 1, 2 or 3 for the normal (N), moderate drought (MD), severe drough (SD) and extreme drough (ED) intensities, respectively. Table III shows the intensity classes and their respective grades, as well as the annual drought classification system that established the classes of “Normality”, “Attention”, “Alert” and “Emergency”, based on the possible sums of notes (global note).

RESULTS AND DISCUSSION

Table IV shows the average annual and long term precipitation of the nine AUs as well as of the entire Doce River Basin. From these data, it is possible to analyze a marked variability of mean precipitation in the basin, both in time (quarters) and in space (AUs). This confirms the importance of applying

TABLE I
Relation between PNP, SPI, DM and RAI values and drought intensity.

PNP (Cunha 2008)		SPI (McKee et al. 1993)	
Interval	**Drought intensity**	**Interval**	**Drought intensity**
0.85 ≤ PNP < 1.10	Normal	-1.00 < SPI ≤ 0.00	Mild Drought
0.75 ≤ PNP < 0.85	Moderate Drought	-1.50 < SPI ≤ -1.00	Moderate Drought
0.50 ≤ PNP < 0.75	Severe Drought	-2.00 < SPI ≤ -1.50	Severe Drought
PNP < 0.50	Extreme Drought	SPI ≤ -2.00	Extreme Drought

DM (Gibbs and Maher 1967)		RAI (Rooy 1965)	
Deciles	**Drought intensity**	**Interval**	**Drought intensity**
10-9	Very Humid	-0.50 < RAI < 0.50	Mild Drought
8-7	Humid	-2.00 < RAI ≤ -0.50	Moderate Drought
6-5	Next to Normal	-3.00 < RAI ≤ -2.00	Severe Drought
4-3	Dry	-4.00 < RAI ≤ -3.00	Extreme Drought
2-1	Very Dry	RAI ≤ -4.00	Dries Soft

TABLE II
Drought intensity classification based on the PNP, DM, RAI and SPI indices and class limits proposed and adopted in the present study.

Intensity	Range of indexes values			
	PNP	**DM**	**RAI**	**SPI**
Normal	0.90 ≤ PNP < 1.10	5 and 6	-2.00 < RAI ≤ 2.00	-0.84 < SPI ≤ 0.84
Moderate Drought	0.81 ≤ PNP < 0.90	3 and 4	-3.00 < RAI ≤ -2.00	-1.28 < SPI ≤ -0.84
Severe Drought	0.75 ≤ PNP < 0.81	2	-4.00 < RAI ≤ -3.00	-1.65 < SPI ≤ -1.28
Extreme Drought	PNP < 0.75	1	RAI ≤ -4.00	SPI ≤ -1.65

the drought severity indices in the sub-basins and not simply in the Doce River Basin.

The highest annual precipitation occurred in the AU 2, while the lowest annual average was in the AU 7, being possible to verify a great spatial variability of the precipitation in the Doce Basin, with amplitude greater than 400 mm.

Cupolillo et al. (2008) studied the climatology of the Doce River Basin and its relation with the local topography, from 1973 to 2002, verifying that the largest average annual precipitations occurred in the Santo Antônio River Basin (AU 3) and the Piracicaba River Basin (AU 2), and the lowest in the Caratinga River Basin (AU 5). The authors state that frontal systems and tropical convection are the

TABLE III
Notes for the drought intensity classes and annual drought classification system based on the global grading intervals.

Intensity	Grade
Normal	0
Moderate Drought	1
Severe Drought	2
Extreme Drought	3
Climatic condition	**∑ Indexes grades**
Normality	0 - 2
Attention	3 - 6
Alert	7 - 9
Emergency	10 - 12

TABLE IV
Average quarterly and annual precipitation, in mm, of the analysis units (AUs) and of the catchment area of the Doce River.

AUs	P quarterly (mm)				P anual (mm)
	Jan/Feb/Mar	Apr/Mar/June	July/Aug/Sept	Oct/Nov/Dec	
AU1	531.3	118.6	77.1	592.9	1,319.9
AU2	572.9	128.0	73.9	661.7	1,436.5
AU3	500.3	120.1	60.0	633.7	1,314.2
AU4	383.1	102.4	59.6	535.4	1,080.4
AU5	378.5	99.1	54.9	536.4	1,068.9
AU6	409.9	111.2	65.9	556.3	1,143.2
AU7	365.5	113.7	61.9	490.3	1,031.3
AU8	352.7	139.6	90.7	505.5	1,088.4
AU9	355.8	137.8	104.5	495.8	1,093.9
Doce	427.8	118.9	72.1	556.4	1,175.2

AU1 = Piranga River Basin; AU2 = Piracicaba River Basin; AU3 = Santo Antônio River Basin; AU4 = Suaçuí River Basin; AU5 = Caratinga River Basin; AU6 = Manhuaçu River Basin; AU7 = Guandu River Basin; AU8 = Santa Maria do Doce River Basin; AU9 = São José River Basin; and Doce = Doce River Basin.

main factors of rainfall formation in the basin, and the topography causes it to be unevenly distributed.

The results of the PNP, DM, RAI and SPI indices for the nine AUs of the Doce River Basin, presented in Table V, are approached together with the drought intensities classification system for all years of the base period, according to the overall rating.

It is observed that the numerical analysis of the results of the indices is difficult to interpret and, therefore, it becomes more interesting the evaluation according to its classifications of droughts by different colors in Table V. It is verified that the class SD, when present, is always accompanied by at least the class MD and never only of the class N. In other words, when one of the indexes detected SD, all others detected at least MS. This shows that the more intense the anomaly, the more homogeneous the indices are in the detection of the drought.

The global classification (Table VI), applied to the drought classification system, showed that, in general, the Doce River Basin in the period from 1985 to 2015 had drought as an anomaly of interannual variability and non-permanent , that is, it remained recurrent over the years of the historical series evaluated.

Also, it is possible to note that in many years there have been no drought events in the AUs of the Doce River Basin, showing the non-permanent characteristic of this climatic anomaly. On the other hand, it is important to note that, when present, the drought covered several AUs in the basin, such as in the years of 1986/1987, 1989/1990, 1994/1995, 1997/1998, 1998/1999, 2000/2001, 2002/2003, 2007/2008, 2012/2013 and 2014/2015.

In 10 years of the studied series all the AUs were classified under “Normal” conditions, and these years were not consecutive, except for the years 2003/2004 and 2004/2005 when the 9 AUs maintained this climatic condition. In the others, whenever one year was in the condition of “Normal” throughout the basin, the following year at least one AU received some more aggravating drought classification.

It is observed that every 7 years, approximately, the Doce River Basin presents a climatic condition of prominence in relation to drought events for most

TABLE V

Results of PNP, DM, RAI and SPI indices related to the classes of drought intensity proposed in the global classification.

Hidrological year	AU1				AU2				AU3				AU4				AU5				AU6				AU7				AU8				AU9			
	PNP	DM	RAI	SPI	PNP	DM	RAI	SPI	PNP	DM	RAI	SPI	PNP	DM	RAI	SPI	PNP	DM	RAI	SPI	PNP	DM	RAI	SPI	PNP	DM	RAI	SPI	PNP	DM	RAI	SPI	PNP	DM	RAI	SPI
1985/1986	0.97	5	-0.50	-0.13	0.93	5	-1.31	-0.43	0.95	5	-0.99	-0.30	0.93	4	-1.22	-0.40	0.88	3	-1.95	-0.68	0.85	2	-2.59	-0.91	0.92	5	-1.24	-0.34	0.87	3	-1.88	-0.66	0.92	5	-1.01	-0.30
1986/1987	0.93	4	-1.19	-0.38	0.89	3	-2.20	-0.76	0.81	1	-3.98	-1.41	0.79	2	-3.60	-1.37	0.81	2	-3.20	-1.18	0.92	4	-1.37	-0.44	0.99	6	-0.08	0.04	0.88	3	-1.84	-0.64	0.82	3	-2.19	-0.77
1987/1988	1.01	6	0.09	0.09	1.04	6	0.78	0.34	1.00	6	-0.10	0.01	1.07	7	1.02	0.45	1.08	7	1.19	0.50	0.99	6	-0.22	-0.03	0.83	2	-2.58	-0.82	0.90	4	-1.52	-0.51	0.90	4	-1.29	-0.41
1988/1989	0.94	4	-1.17	-0.37	0.89	3	-2.21	-0.76	0.90	4	-2.08	-0.69	0.88	3	-1.98	-0.70	0.90	3	-1.69	-0.57	0.93	4	-1.16	-0.37	0.91	4	-1.27	-0.36	0.96	5	-0.62	-0.17	0.82	3	-2.26	-0.80
1989/1990	0.85	3	-2.63	-0.94	0.93	4	-1.36	-0.45	1.00	7	0.03	0.06	0.91	4	-1.59	-0.55	0.88	3	-2.01	-0.70	0.81	2	-3.22	-1.16	0.86	3	-2.02	-0.62	0.93	5	-1.09	-0.35	0.83	3	-2.04	-0.71
1990/1991	1.08	7	1.33	0.56	1.00	6	0.01	0.05	0.94	5	-1.17	-0.36	1.21	9	3.30	1.29	1.24	10	3.81	1.41	1.13	8	1.98	0.81	1.06	7	0.77	0.35	1.22	9	3.25	1.20	1.20	8	2.29	0.93
1991/1992	1.10	8	1.58	0.66	1.12	8	2.22	0.87	1.19	9	3.29	1.33	1.23	10	3.53	1.37	1.13	8	2.09	0.82	0.98	6	-0.29	-0.05	0.85	3	-2.20	-0.68	1.11	8	1.55	0.62	1.17	8	1.92	0.80
1992/1993	0.98	6	-0.33	-0.07	1.09	8	1.65	0.67	1.05	8	0.86	0.40	1.12	8	1.85	0.76	1.02	6	0.35	0.19	0.96	5	-0.65	-0.18	0.87	3	-2.00	-0.61	0.91	4	-1.37	-0.45	0.97	6	-0.34	-0.05
1993/1994	1.00	6	0.02	0.06	1.07	7	1.25	0.52	0.89	3	-2.37	-0.80	1.06	7	0.92	0.41	0.99	5	-0.25	-0.03	0.98	6	-0.43	-0.10	1.10	8	1.27	0.53	1.03	6	0.38	0.20	0.99	6	-0.16	0.02
1994/1995	0.82	2	-3.33	-1.22	0.83	1	-3.40	-1.23	0.85	2	-3.26	-1.13	0.84	2	-2.67	-0.98	0.79	1	-3.43	-1.28	0.74	1	-4.58	-1.73	0.52	1	-7.15	-2.78	0.76	2	-3.56	-1.36	0.66	1	-4.14	-1.63
1995/1996	0.93	4	-1.27	-0.41	0.99	6	-0.19	-0.02	1.03	7	0.50	0.25	0.97	5	-0.55	-0.15	0.98	5	-0.27	-0.04	0.94	4	-0.96	-0.29	0.81	1	-2.90	-0.94	1.04	6	0.61	0.29	0.92	5	-0.97	-0.29
1996/1997	1.26	10	4.20	1.59	1.27	10	4.92	1.80	1.26	10	4.58	1.79	1.27	10	4.13	1.57	1.24	9	3.76	1.39	1.35	10	5.39	1.98	1.51	10	6.63	2.23	1.33	10	4.73	1.67	1.16	7	1.76	0.74
1997/1998	0.94	5	-1.10	-0.35	1.07	7	1.27	0.53	0.94	5	-1.25	-0.39	0.81	2	-3.24	-1.22	0.99	6	-0.14	0.00	0.85	3	-2.55	-0.89	0.90	4	-1.54	-0.45	0.78	2	-3.32	-1.26	0.67	1	-4.10	-1.61
1998/1999	0.88	3	-2.25	-0.79	0.85	2	-2.95	-1.05	0.90	3	-2.16	-0.72	0.89	4	-1.82	-0.64	0.83	2	-2.79	-1.01	0.83	2	-2.93	-1.05	0.92	5	-1.17	-0.32	0.78	2	-3.24	-1.22	0.78	2	-2.71	-0.99
1999/2000	1.12	8	1.96	0.80	1.13	8	2.41	0.94	1.08	8	1.32	0.58	1.10	7	1.59	0.67	1.03	7	0.46	0.23	1.06	8	0.92	0.41	1.10	8	1.31	0.54	1.10	7	1.51	0.61	1.19	8	2.08	0.86
2000/2001	0.84	2	-2.87	-1.03	0.79	1	-4.10	-1.51	0.85	2	-3.27	-1.14	0.76	1	-4.03	-1.56	0.73	1	-4.53	-1.75	0.88	3	-2.01	-0.69	0.81	2	-2.84	-0.92	0.91	4	-1.39	-0.46	1.02	6	0.21	0.16
2001/2002	1.16	9	2.67	1.06	1.15	9	2.66	1.03	1.18	9	3.10	1.26	1.28	10	4.26	1.62	1.25	10	3.94	1.45	1.16	8	2.42	0.96	1.28	10	3.64	1.32	1.30	10	4.35	1.55	1.42	10	4.67	1.73
2002/2003	1.03	7	0.51	0.25	1.09	7	1.55	0.63	1.00	6	0.03	0.06	0.87	3	-2.26	-0.82	0.99	5	-0.21	-0.02	1.05	7	0.74	0.34	0.91	4	-1.33	-0.38	0.68	1	-4.68	-1.87	0.65	1	-4.32	-1.72
2003/2004	1.23	9	3.67	1.41	1.22	10	3.97	1.48	1.19	9	3.37	1.36	1.18	8	2.71	1.08	1.15	8	2.41	0.93	1.23	9	3.55	1.36	1.10	7	1.27	0.53	1.14	8	2.06	0.80	1.36	10	4.00	1.51
2004/2005	1.25	10	4.02	1.53	1.15	9	2.81	1.08	1.24	10	4.26	1.68	1.22	9	3.38	1.31	1.30	10	4.70	1.70	1.33	10	5.15	1.90	1.41	10	5.23	1.81	1.35	10	5.12	1.79	1.32	9	3.57	1.37
2005/2006	0.82	1	-3.33	-1.22	0.92	4	-1.60	-0.53	0.92	4	-1.61	-0.52	1.02	6	0.27	0.16	0.91	4	-1.49	-0.50	0.86	3	-2.36	-0.82	0.95	6	-0.71	-0.17	0.97	5	-0.50	-0.12	0.91	4	-1.07	-0.32
2006/2007	1.08	7	1.22	0.52	0.95	5	-1.01	-0.32	1.05	7	0.83	0.39	1.15	8	2.24	0.91	1.08	8	1.26	0.52	1.19	9	2.98	1.16	1.21	9	2.74	1.03	1.10	7	1.51	0.61	1.22	9	2.47	1.00
2007/2008	0.95	5	-0.92	-0.28	0.90	3	-2.04	-0.70	0.84	1	-3.47	-1.21	0.78	1	-3.76	-1.44	0.81	2	-3.13	-1.15	0.78	1	-3.84	-1.42	0.81	2	-2.86	-0.93	0.74	1	-3.86	-1.50	0.73	2	-3.37	-1.28
2008/2009	1.35	10	5.66	2.07	1.27	10	4.90	1.80	1.32	10	5.67	2.18	1.20	9	3.01	1.19	1.23	9	3.63	1.35	1.24	10	3.71	1.42	1.27	9	3.44	1.26	1.15	9	2.22	0.86	1.24	9	2.64	1.06
2009/2010	0.84	2	-2.80	-1.01	0.95	5	-1.01	-0.31	0.94	4	-1.34	-0.42	0.94	5	-1.04	-0.33	0.91	4	-1.56	-0.52	0.95	5	-0.82	-0.24	1.05	7	0.67	0.32	1.02	6	0.32	0.18	0.97	5	-0.36	-0.06
2010/2011	1.12	8	1.97	0.80	0.89	2	-2.22	-0.77	0.98	6	-0.49	-0.12	0.95	5	-0.90	-0.28	1.20	9	3.21	1.20	1.20	9	3.10	1.21	1.17	8	2.18	0.85	1.14	8	2.04	0.79	1.08	7	0.87	0.41
2011/2012	1.18	9	2.94	1.15	1.16	9	2.91	1.12	1.16	8	2.72	1.12	1.05	6	0.71	0.33	1.00	6	-0.06	0.03	1.05	7	0.80	0.37	1.02	6	0.20	0.14	1.09	7	1.24	0.51	1.08	7	0.84	0.40
2012/2013	0.87	3	-2.38	-0.84	0.83	2	-3.33	-1.20	0.87	3	-2.65	-0.90	0.86	3	-2.27	-0.82	0.94	4	-0.93	-0.29	0.97	5	-0.51	-0.13	0.95	5	-0.76	-0.18	0.84	3	-2.32	-0.84	0.85	4	-1.89	-0.65
2013/2014	0.74	1	-4.72	-1.81	0.91	4	-1.88	-0.64	0.85	2	-3.14	-1.09	0.97	6	-0.51	-0.14	1.04	7	0.65	0.30	1.03	7	0.54	0.27	1.18	9	2.28	0.88	1.22	9	3.18	1.18	1.41	10	4.60	1.70
2014/2015	0.75	1	-4.42	-1.68	0.72	1	-5.68	-2.19	0.83	1	-3.61	-1.27	0.74	1	-4.37	-1.71	0.66	1	-5.70	-2.29	0.74	1	-4.55	-1.72	0.74	1	-3.92	-1.34	0.74	1	-3.79	-1.46	0.76	2	-2.99	-1.11

Drought intensity classification: N= Normal □; MD= Moderate Drought □; SD= Severe Drought □; ED= Extreme Drought □.

TABLE VI
Alert classification of the AUs of the Doce River Basin from 1985 to 2015 based on the global classification.

Hydrological Year	Grade								
	AU1	AU2	AU3	AU4	AU5	AU6	AU7	AU8	AU9
1985/1986	0	0	0	1	2	5	0	2	0
1986/1987	1	3	8	8	7	1	0	2	3
1987/1988	0	0	0	0	0	0	4	2	2
1988/1989	1	3	2	2	2	1	1	0	3
1989/1990	4	1	0	1	3	6	3	0	3
1990/1991	0	0	0	0	0	0	0	0	0
1991/1992	0	0	0	0	0	0	3	0	0
1992/1993	0	0	0	0	0	0	2	1	0
1993/1994	0	0	3	0	0	0	0	0	0
1994/1995	6	7	6	5	8	12	12	8	11
1995/1996	1	0	0	0	0	1	7	0	0
1996/1997	0	0	0	0	0	0	0	0	0
1997/1998	0	0	0	7	0	4	2	7	11
1998/1999	3	5	3	2	5	5	0	7	6
1999/2000	0	0	0	0	0	0	0	0	0
2000/2001	5	10	6	10	12	3	6	1	0
2001/2002	0	0	0	0	0	0	0	0	0
2002/2003	0	0	0	3	0	0	1	12	12
2003/2004	0	0	0	0	0	0	0	0	0
2004/2005	0	0	0	0	0	0	0	0	0
2005/2006	7	1	1	0	1	3	0	0	1
2006/2007	0	0	0	0	0	0	0	0	0
2007/2008	0	3	7	9	6	9	6	10	8
2008/2009	0	0	0	0	0	0	0	0	0
2009/2010	5	0	1	0	1	0	0	0	0
2010/2011	0	4	0	0	0	0	0	0	0
2011/2012	0	0	0	0	0	0	0	0	0
2012/2013	4	6	4	3	1	0	0	3	2
2013/2014	12	1	6	0	0	0	0	0	0
2014/2015	11	12	7	12	12	12	10	10	6

Climatic condition classification: Normality ■, Attention ■, Alert ■ and Emergency ■.

of the AUs, noting that during this time interval there are other important adverse conditions, such as the years 1997/1998, 1998/1999, 2001/2002 and 2012/2013. It is also observed that the climatic condition of the AUs was more severe in the second part of the base period analyzed, that is, the droughts became more intense in the last 15 years.

It is worth mentioning that the precipitation regime is directly influenced by global atmospheric phenomena, such as El Niño, La Niña and ocean oscillation (Garcia 2006). Moreira (1999) states that El Niño promotes a lower volume of rainfall and La Niña promotes lower temperatures, considerably altering the rainfall regime of the southeastern region of Brazil.

A major El Niño event was evidenced for the year 1997/1998, with impacts on various parts of the country. Minuzzi et al. (2005) found that the El Niño of 1997/1998 caused below-average precipitation in the State of Minas Gerais, in addition to noticing an El Niño interval every 4 years. This study corroborates the results presented in Table VI, where 4 years earlier (1994/1995) and 4 years later (2000/2001) climatic conditions were alarming in several AUs.

It should be noted that in the years 1994/1995, 2000/2001 and 2014/2015, the drought affected practically the whole Doce River Basin and, therefore, Figure 2 shows a detail of the climatic condition in the different AUs in those years.

The 1994/1995 hydrological year was one of the most critical years for the Doce River Basin. In this period, all AUs suffered from drought, three of them under "Attention" conditions (AU 1, AU 3 and AU 4), three in "Alert" (AU 2, AU 5 and AU 8) and the others in "Emergency" (AU 7 and AU 9). It is clear that in the year 1994/1995 the problem was more severe in the low Doce River compared to the bedside areas of the basin (high and part of the middle Doce River). The El Niño event of 1994/1995, despite being of moderate intensity, was significant for some regions of Minas Gerais (Minuzzi et al. 2005) and may have influenced this behavior.

In 2000/2001 the drought also took up a large part of the basin, in which seven of the nine AUs presented critical periods of lack of rainfall. Although in the majority of the AUs drought events were verified, two AUs (AU 8 and AU 9), located close to the mouth of the basin, did not suffer with this climatic anomaly in that period. This fact shows the importance of evaluating drought in units of analysis and not only in the river basin as a whole. In the year 2000, Brazil experienced serious difficulties due to the lack of rainfall and the consequent crisis of electricity supply (Grün 2005), which caused a "blackout" in several parts of the country.

The period of 2014/2015 was undoubtedly the worst year of drought evidenced in the Doce River Basin in the base period analyzed. In seven of the nine AUs the climatic condition reached an "Emergency" level. A critical year like 2014/2015 is capable of producing reflections for several years, since it can compromise reservoir levels, as well as recharge of aquifers, consequently reducing the flow of water during the dry season. This fact may further aggravate the problem of water scarcity in most of the municipalities of the basin.

As already pointed out, drought is an anomaly that can not be avoided and, therefore, one must always take preventive action. Therefore, constant monitoring of drought rates and the application of the annual drought classification system can be a key tool for the planning and management of water resources in the basin.

It is worth mentioning that an alert system capable of achieving satisfactory results goes beyond the monitoring of drought rates. There are several other factors that should be taken into account, such as: water storage levels in reservoirs and rivers, conflicts over water use, suspension and denial of water use grants, and water quality decay in watercourses.

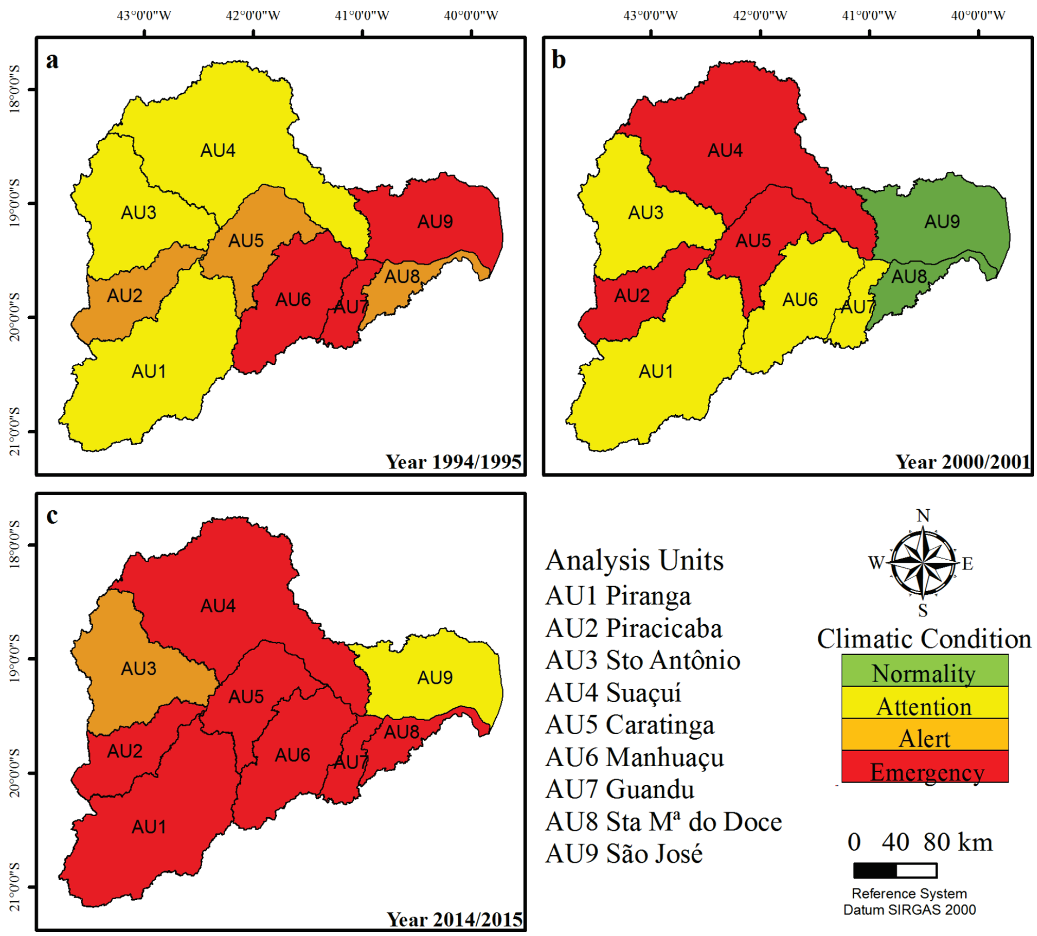

Figure 2 - Climatic conditions of the 1994/1995 (**a**), 2000/2001 (**b**) and 2014/2015 (**c**) hydrological years for the Doce River Basin AUs.

As a proposal for future studies it is recommended the application of the drought classification system based on drought determination indexes that require, in addition to precipitation series, other data, such as: temperature, soil moisture and evapotranspiration, so that this classification can be related to flow values and/or socioeconomic indexes of the Doce River Basin.

CONCLUSIONS

Droughts have become more intense in the last 15 years, since the climatic condition of the AUs was more severe in the second part of the base period analyzed. The most critical hydrological years of the Doce River Basin in relation to the drought were 1994/1995, 2000/2001 and 2014/2015, the latter being the most critical in the baseline period analyzed. The global classification of the drought indexes, based on the annual scale, was an important management tool to be used in the classification system of annual droughts, allowing to verify that the Doce River Basin presents a severe climatic condition of drought on average, every seven years.

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AUTHOR CONTRIBUTIONS

RPCL Selection of the area of studies; Analysis and consistency of the pluviometric database, structuring and implementation of the methodology used in the work; Formulation of tables, graphs, maps and discussion of results. **DDS** Adequacy of methodologies for study area; Discussion of results; Final revision of the authors contributions of all versions presented. **SBP** Selection of rainfall stations; Definition of the methodology of filling in the faults and spatialization of information. **MCM** Interpolation methodology for spatialization purposes; Analysis and discussion of the results of the article. **JBMCP** Organization of the database; Fault filling in the historical precipitation series; Formulation of tables and graphs. **CDC** Implementation of spatialization procedures and consistency analysis of historical data series; Final revision of the English versions of the article. **AAAE** Support in the process of selecting the rainfall stations to be used in the study area and in the analysis and discussion of the results obtained; Structuring of bibliographic references.

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