Analysis of the Extremes of Precipitation and Streamflow Using Standardized Index on Spring Reservoirs of Paraíba do Sul Watershed (Southeast Region, Brazil)

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Abstract: Reducing the impacts on water resources is necessary and urgent in order to maintain our way of life for future generations. In this regard, understanding water behavior and interactions on all scales is fundamental to achieving effective improvements in its management. Hydrometeorological extremes can cause big social, environmental and economic impacts on countries. Paraíba do Sul Watershed is located in the Southeast region of Brazil, and covers the states of Minas Gerais, Rio de Janeiro and São Paulo. This area has a large population density and is relevant to the economy of the country. This study was carried out in springs of Paraíba do Sul Watershed, where there are three water reservoirs used for water storage for electricity generation, water supply and flood control. The reservoirs are called Paraibuna, Santa Branca and Jaguari. The monthly series used contain 45 years of observations, from January 1972 to December 2016. Seven meteorological stations and three fluviometric measurement points were selected. The precipitation series underwent treatment for data quality control and gap filling before analysis. The natural flow series were made available by Brazilian National Operator of Electric System, and show the sum of the observed flow rate and the withdrawals made by the hydraulic system for various uses. The Standardized Precipitation Index (SPI) was used to calculate precipitation anomaly and the Streamflow Drought Index (SDI) was used for streamflow anomaly. Both indexes were calculated at the scales of 3, 6 and 12 months, which allowed an accurate evaluation of the climatic extremes over the hydrological years, and the influence of dry and wet semesters and quarters on the annual series. In the hydrological year series 79 occurrences of precipitation anomalies were observed, of which 39 dry and 40 wet ones. There were also 37 streamflow anomalies, of 15 were dry and 22 were wet. Precipitation anomalies represent a higher frequency of occurrence in the basin. The SDI indices were correlated with the SPI indices in different scales using Pearson correlation coefficient (r). The SDI index calculated for Paraibuna has a high correlation ($r > 0.5$) with annual SPI for all stations and the wet season for the Redenção da Serra station. Santa Branca has a correlation greater than $r > 0.5$ with annual SPI, wet semester and wet quarter for all stations. For Jaguari the correlations between annual SPI, wet semester, dry semester and wet quarter and SDI were greater than $r > 0.5$ for all stations. Most of the years do not show significant anomaly and are characterized as normal in 74.3% of the years of precipitation and 71.9% of streamflow. It is concluded that in most of the series the streamflow anomalies correspond to the precipitation anomaly in frequency, but do not correspond to the intensity. In the region of the Paraibuna reservoir the humid streamflow extremes clearly correspond to extremes of precipitation in the stations around the reservoir, although the dry streamflow extremes do not present the same clarity. In the region of the Santa Branca and Jaguari reservoirs the wet and dry streamflow extremes correspond to extremes of precipitation.

Key Words: water resources; standardized index; extreme precipitation; extreme streamflow; Paraíba do Sul Watershed; Brazilian Southeast Region.

1 Introduction

Water is essential for the survival and the way of life in society. Besides the biological importance, water has strategic essential in development. It is crucial to understand hydrological systems to achieve universal service to society. In order to promote the necessary protection of these resources, it is important to support the freshwater access. It is mandatory to carry out the production and agriculture, within the environmental limits, which allow for the renewal of resources without harm for the users.

Evaluating the extremes of precipitation and streamflow allows us to understand the hydrological cycle in the region. This way it is possible to create prevention, adaptation and mitigation strategies for the natural disasters due to climatic extremes. Standardized indexes allow the comparison of several regions with the most diverse types of climatic, economic, social and environmental characteristics. It is also possible to analyze the climate extremes individually and correlated.

The Paraíba do Sul River watershed is in the Southeast Region of Brazil between the states of São Paulo (SP), Minas Gerais (MG) and Rio de Janeiro (RJ). The springs are in the state of São Paulo. Three of the four main reservoirs are in this state: Paraibuna, Santa Branca and Jaguari. The Southeast Region has an important economic and political importance. The greatest population density of the country is in this area. The watershed is fundamental for the water supply of the metropolitan area of Rio de Janeiro via a complex hydraulic structure of transposition. The system serves municipalities in the entire states of SP, MG and RJ. The reservoirs are also responsible for storing water for electricity generation. The three states have hydroelectric generation plants. The system is also responsible for flow regulation in order to minimize the risk of natural disasters.

Water is a strategic resource; therefore, it is included in all discussions on sustainable development with focus on improvements in the management of water resources, providing access to water supply and basic sanitation. These actions are the best way for social and economic development, preservation of the environment and guarantee of the necessary resources for this and the generations to come. Access to water varies based on physical water availability, resource management, the storage and access to the users. Creating new technologies and more efficient management models is a challenge. Understanding climatic extremes is part of the strategy for adaptation and mitigation of the impact of droughts and floods.

2 Materials and methods

2.1 Characterization of the Study Area

The reservoirs of Paraibuna, Santa Branca and Jaguari (Table 1) belong to the Paraíba do Sul Watershead. The springs of the reservoirs are in compartments in the Water Resources Management Unit 02 (UGRHI 02). UGRHI 02 is in the eastern part of the state of São Paulo and borders the states of Rio de Janeiro and Minas Gerais, Southeastern Brazil (Figure 1). The size of the drainage areas is 4,272.15, 797.99 and 1,319 km² respectively. The main rivers of Paraibuna reservoir are Paraitinga and Paraibuna. Santa Branca reservoir includes Capivari, Salto and Vargem Grande rivers. Jaguari resevoir consists of Peixe and Jaguari rivers (CBH-PS 2016a, CBH -PS 2016b).

The region is located between the parallels 22º0 'S and 24º0' S and meridians 45º0 'W and 46º30' W. The altitude is between 400m and 2000m in relation to sea level. The meteorological stations are between 560 and 800 m of altitude. The springs are located in the mountainous region of the watershed. The climate is characterized as megathermal subtropical, with monthly air temperature between 18 and 24 ºC. The maximum annual precipitation is about 2000 mm in the mountainous region (Marengo and Alves 2005, AGEVAP 2006, AGEVAP 2014). Rainfall in the study area is related to the winter and summer seasons, with the driest period observed in winter (from June to August), while the rainiest period is concentrated in the summer (December to February).

Table 1: Volume of Spring Reservoirs of the Paraíba do Sul River Watershed. Source: ANA (2015a)

ID	Reservoir	Maximum (hm³)	Minimum (hm³)	Useful (hm³)	Distribution
A	Paraibuna	4731.7	2.095.6	2.636.1	61%
B	Santa Branca	439.0	131.0	308.0	7%
C	Jaguari	1235.6	443.1	792.5	18%

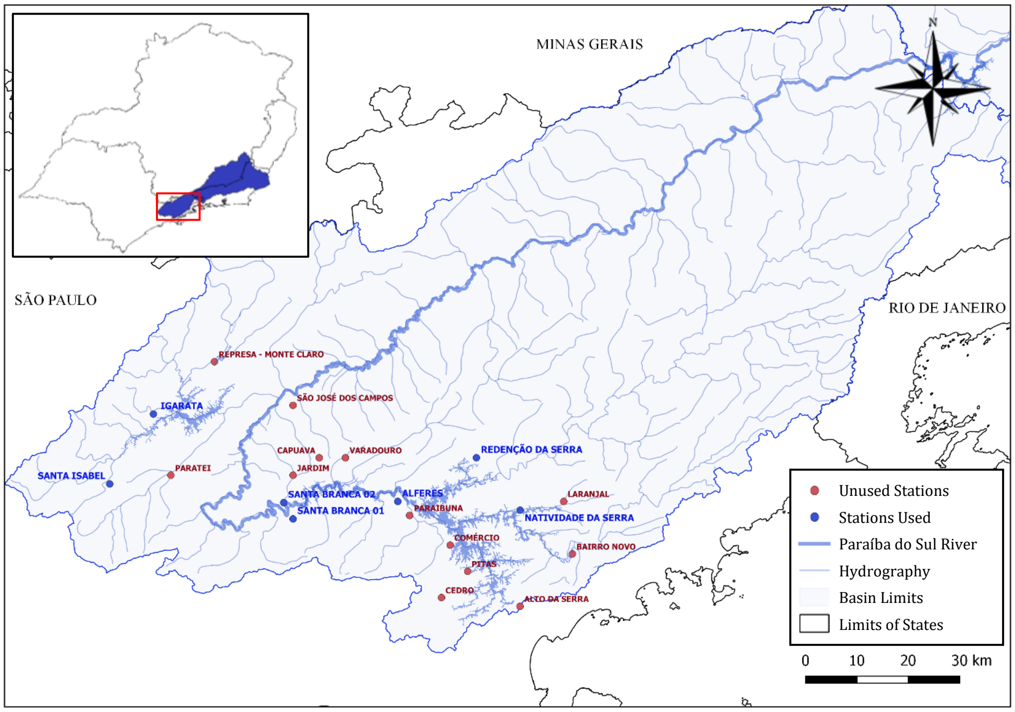

Figure 1: Meteorologic Station Location and Hydrography of the Study Area

2.2 Observed rainfall series

The monthly rainfall series were obtained through the "HidroWeb" system of the National Water Agency (Agência Nacional de Águas - ANA) and the Hydrological Data Bank of the Department of Water and Electric Power (Departamento de Águas e Energia Elétrica -

DAEE) in the State of São Paulo. Twenty stations (Table 2) were selected around the three reservoirs, all of them with a minimum of 30 years of precipitation data.

The monthly rainfall series has data from November 1927 to the present day. Eighteen stations are operated by the DAEE, one by electric power distributor - Light and one by the Mineral Resources Research Company (Companhia de Pesquisa de Recursos Minerais - CPRM). All the stations used are conventional and operate by rain gauge.

Table 2: Pre-selected stations - Source: ANA 2018

Nº	Stations	Cod.	Latitude	Longitude	Altitude	Operator	Serie - Beginning	Serie - End
1	ALFERES	2345034	-23.36	-45.68	670	DAEE-SP	Jan/43	May/18
2	IGARATA	2346344	-23.20	-46.15	780	DAEE-SP	Sep/72	Jun/18
3	NATIVIDADE DA SERRA	2345032	-23.38	-45.45	720	DAEE-SP	Jan/40	Jun/18
4	REDENÇÃO DA SERRA	2345023	-23.28	-45.53	740	DAEE-SP	Sep/53	May/18
5	SANTA BRANCA 01	2345037	-23.40	-45.88	670	DAEE-SP	Jun/42	Apr/18
6	SANTA BRANCA 02	2345071	-23.36	-45.90	573	CPRM	Jun/52	Oct/18
7	SANTA ISABEL	2346019	-23.33	-46.23	690	DAEE-SP	May/37	May/18
8	ALTO DA SERRA	2345176	-23.56	-45.45	760	DAEE-SP	Sep72	Oct/14
9	BAIRRO ALTO	2345041	-23.46	-45.35	710	DAEE-SP	Jan/40	Dec/99
10	CAPUAVA	2345156	-23.28	-45.83	660	DAEE-SP	Jan/60	Dec/00
11	CEDRO	2345046	-23.55	-45.60	750	DAEE-SP	Sep/69	Nov/95
12	COMÉRCIO	2345154	-23.45	-45.58	720	DAEE-SP	Mar/43	Sep/03
13	JARDIM	2345029	-23.31	-45.88	660	DAEE-SP	May/62	Jul/97
14	LARANJAL	2345031	-23.36	-45.36	800	DAEE-SP	Jan/70	Mar/01
15	PARAIBUNA	2345102	-23.39	-45.66	650	LIGHT	Nov/27	Oct/03
16	PARATEI	2346018	-23.31	-46.11	600	DAEE-SP	Nov/57	Jun/03
17	PITAS	2345042	-23.50	-45.55	780	DAEE-SP	Mar/43	Dec/93
18	REPRESA - MONTE CLARO	2346006	-23.10	-46.03	630	DAEE-SP	Sep/69	Mar/04
19	SÃO JOSÉ DOS CAMPOS	2345019	-23.18	-45.88	560	DAEE-SP	Nov/42	Nov/03
20	VARADOURO	2345025	-23.28	-45.78	680	DAEE-SP	Mar/43	Dec/94

2.3 Quality control and gap filling of precipitation time series

It is necessary to use homogeneous and continuous series (without failures) for the climatic analyzes. Therefore, techniques of quality analysis and fault filling are proposed by Allen et al. (1998) and Kite (1988). These techniques are also used for monthly precipitation series by Brito et al. (2017), Lyra et al. (2014a, 2014b, 2017a, 2017b), Oliveira-Júnior et al. (2012) and Uele (2013; 2017).

Five stations closest to the station to be filled are selected for the quality control and gap filling. Correlation analysis is performed (Person correlation coefficient) using only the months that have not contain faults between the station to be filled and the five nearest stations after the selection. The stations that series has no correlation higher than $r > 0.50$ with the reference series or with series of the stations closest to the reference station were removed (Lyra et al. 2014b).

Gap filling is performed by linear regression methodology between the precipitation series (Yi) (dependent variable) and reference series (Xi) (independent variable). The reference series are constructed using the arithmetic averages of the five nearest stations, Alferes, Santa Branca 01 and Santa Branca 02 the four stations nearest and with the highest possible r, as previously described. The equation is described in a simple linear regression model by equation 01:

$$Yi = b0 + b1Xi \quad (01)$$

where:
$b0$ and $b1$ = model coefficients.
i = i-th observation of the series
Xi = arithmetic mean of the climate series.

The precipitation series data is matched chronologically to adjust the coefficient of the linear model ($b0$ and $b1$) the. Adequacy of the method is evaluated by the values of the coefficient ($b1$) and the coefficient of determination (r^2) of the regression. The method is considered satisfactory when angular coefficient ($b1$) is between 0.7 and 1.3 and the coefficient of determination (r^2) is greater than or equal to 0.7 (Allen et al. 1998).

The quality control is performed observing comparing the reference series Xi, with the observed series Yi. An exploratory analysis is carried to identify outliers based on the expected climatic intervals for the data based on the series. This analysis is carried out based on the characterization of the region's climate, the exploratory data analysis, using boxplot and observation of the extremes expected for the series. The outliers are compared with the mean precipitation of the reference series of the correlated stations and the station analyzed. The stations that submitted to the quality treatment present satisfactory results. In this comparison, the values of monthly rainfall that deviated by about 75 % from the trend determined by the series are considered non-representative and are withdrawn from the series (Lyra et al. 2004; Oliveira-Júnior et al. 2012)

2.4 Natural Streamflow Series

The series of monthly Natural Streamflow Series are chosen, because these series consider the observed flows plus the withdrawals from the system. This methodology is used by the National Eletric System Operator (Operador Nacional do Sistema Elétrico - ONS) (ONS 2009, 2016, 2018a, 2018b, 2018c).

The methodology consists first of calculating the incremental streamflow, which allows the calculation of the natural streamflow. The equations 02 and 03 are used (ONS 2009).

$$Qinc = Qafl - Qdefmp + Quso + Qevp \quad (02)$$

where:
$Qinc$ = incremental natural streamflow between utilization and upstream (m^3/s).
$Qafl$ = flow to the reservoir obtained from (1) (m^3/s).
$Qdefmp$ = effluent flow from upstream reservoirs, properly propagated in reservoir condition (m^3/s).
$Quso$ = flow relative to the incremental basin consumptive uses (m^3/s).
$Qevp$ = reservoir evaporation flow rate obtained from the coordinate polynomial x area and monthly reservoir net evaporation vector (m^3/s).

$$Qnat = Qnatp + Qinc\ con \quad (03)$$

where:
$Qnat$ = natural streamflow at the measurement point (m3 / s).
$Qnatp$ = natural streamflow of upstream reservoirs, in natural condition (m^3 / s).

Qinc con = incremental natural flow rate consisted between recovery and uptake of amount.

Three points of natural streamflow measurement are used. These being located one in each reservoir. The data series are made available by ONS and consist of data from 1931 to the present day. However, the series that coincide with the series of precipitation series are used (ONS 2019).

2.5 Standardized Precipitation Index and Streamflow Drought Index

The Standardized Precipitation Index (SPI), initially proposed by Mc Kee et al. (1993), is used to characterize the precipitation extremes in dry and wet events. The Streamflow Drought Index (SDI), which is analogous to SPI, is used to identify streamflow anomalies proposed by Modarres (2007) Shukla and Wood (2008) Nalbantis and Tsakiris (2009).

The index is calculated by monthly data of precipitation for SPI and streamflow for SDI, considering a series of at least 30 years. A set of months is determined to indicate the analyzed scale which can be 3, 6, 9, 12, 24 or 48 months. These sets represent different scales of interest in rainfall and streamflow. Each data set is fitted to the gamma probability function and then applied to the Z transformation for series normalization to obtain zero mean and standard deviation one. The result is a normalized index, which allows classification of the anomalies and, which can be used for dry and wet periods. The intensity of the extremes is classified according to Table 3 (Mc Kee et al. 1993, Modarres 2007, Shukla and Wood 2008, Nalbantis and Tsakiris 2009).

Table 3: Classification of intensity of SPI and SDI. - Source: Mc Kee et al. 1993

≥ 2.00	Extremely Humid
1.50 a 1.99	Severely Humid
1.00 a 1.49	Moderately Humid
-0.99 a 0.99	Close to Normal
-1.00 a -1.49	Moderately Dry
-1.50 a -1.99	Severely Dry
≤ -2.00	Extremely Dry

The choice of these indexes is because of their versatility and simplicity. They can be used for several time scales and regions with different climates. The analyze is using only precipitation or streamflow data to be calculated. The similarity between SPI and SDI allows a more accurate analysis of the comparative data of precipitation and streamflow (Modarres 2007, Shukla and Wood 2008, Nalbantis and Tsakiris 2009, Rajsekhar et al. 2014).

The SPI is calculated using the monthly precipitation series, after quality control and gap filling at seven stations. The SDI is calculated for monthly natural streamflow series at the three measurement points. Both indices are calculated for 3, 6 and 12 months. The SPI 12 is calculated for the calendar year (January to December) and the hydrological year. The hydrological year begins in the rainy season and goes to the end of the dry period, in the study area from October to September (Marcuzzo and Goularte 2013). SPI 6 is calculated for the dry semester (April to September) and wet semester (October to March).

SPI 3 is calculated for dry season (June to August, winter) and rain season (December to February, summer).

The indexes are calculated by first fitting the precipitation data of each station into a gamma function, where parameters α and β are determined using the Maximum-likelihood method (Thom 1966). After determining the parameters of the gamma function, the cumulative probabilities of precipitation and natural streamflow are calculated for the 3, 6 and 12 month scales according to equation 04:

$$\mathrm{F(x)} = \int_0^{\mathrm{x}} \mathrm{f(x)dx} = \frac{1}{\Gamma(\alpha)\beta^{\alpha}} \int_0^{\mathrm{x}} \mathrm{x}^{\alpha-1}\, \mathrm{e}^{-\frac{\mathrm{x}}{\beta}} \mathrm{dx} \qquad (04)$$

where:
$\mathrm{f(x)}$= is the probability density function
$\Gamma(\alpha)$= is the incomplete gamma function for parameter α, null values are not allowed (Thom 1958)
α = is the shape parameter
β = is the scale parameter
e = is Neper's number (2,718...)

The cumulative probability for both cases, null or not, is calculated by equation 05.

$$F(x) = F(0) + (1 - (F(0))\, G(x) \qquad (05)$$

where:
$F(0)$ = [= $m / (n + 1)$] is the probability of a null value occurring
$G(x)$ = is the cumulative distribution of $F(x)$ with parameters estimated only for rainy periods
m = is the classification of null values in a climatological series
n = is the sample size

Thus, the cumulative distribution $F(x)$ is transformed into a normal distribution for the random variable Z (Equation 06) which corresponds to the SPI value.

$$Z(= (X_i - F_{50})/\sigma \qquad (06)$$

where:
X_i= is the annual rain for the *i* year
F_{50}= is the accumulated rain at 50%
σ = is standard deviation with mean 0 and standard deviation 1 [$N(0,1)$]

3 Results and discussion

3.1 Quality control and gap filling of precipitation time series

Each of the stations Alferes, Santa Branca 01 and Santa Branca 02 have a station removed after carrying out the correlation analysis with the five nearest stations (Table 04), In the three cases, the station removed is Varadouro, because it has shown a correlation with r below 0.50 with the reference stations and the other stations closest to each other.

Table 4: Distance and correlation between the reference station and the five nearest stations. (* station is not used for fault filling).

Reference Station	Nearest Stations	(n)	(km)	(r)
Alferes	Paraibuna	197	3.7	0.92
	Comércio		13.8	0.92
	Varadouro*		13.8	0.41
	Redenção da Serra		17.9	0.88
	Capuava		17.9	0.86
Natividade Da Serra	Laranjal	231	8.7	0.85
	Redenção da Serra		13.8	0.83
	Bairro Alto		14	0.84
	Comércio		15.5	0.87
	Pitas		16.5	0.82
Redenção Da Serra	Natividade da Serra	226	14	0.86
	Paraibuna		17.8	0.87
	Alferes		17.9	0.86
	Comércio		19.1	0.85
	Laranjal		19.4	0.82
Santa Branca 01	Santa Branca 02	226	3.9	0.90
	Jardim		9.2	0.91
	Capuava		13.9	0.88
	Varadouro*		16.5	0.52
	Alferes		20.8	0.91
Santa Branca 02	Santa Branca 01	192	3.9	0.90
	Jardim		6.1	0.86
	Capuava		11.7	0.83
	Varadouro*		15.3	0.51
	São José dos Campos		20.6	0.84
Igaratá	Paratei	217	13.4	0.87
	Represa - Monte Claro		16.3	0.85
	Santa Isabel		17	0.88
	São José dos Campos		27.4	0.88
	Jardim		30.2	0.82
Santa Isabel	Paratei	217	12.1	0.85
	Igaratá		17	0.88
	Represa - Monte Claro		33	0.80
	Jardim		34.2	0.79
	São José dos Campos		35.8	0.86

The series from seven stations are included in the analysis after quality examination and filling of faults (Table 05) and another thirteen are discarded (Table 06). Alto da Serra station is removed because it presents unsatisfactory indexes (r^2 and b1) and Jardim, Laranjal and Varadouro, because they also present unsatisfactory indexes and the size of the faults. The rest of the stations are discarded because of the size of the faults only. Data from some discarded stations is used for the gap filling method.

All the historical series of precipitation in the basin present flaws, so the methodology of completion is definitive to make feasible the proposed analyzes. None of the series has data withdrawal greater than 2 % after quality treatment (Table 05). All data withdrawals considered as spurious improved b and r^2 indices as indicated by Allen et al. (1998).

Tabela 5: Pre and post quality control and gap filling indices (Jan/1972-Dec/2016).

Identification		**Pre**				**Post**				**Difference**
ID	**Station**	**Gap**	**r²**	**a**	**b**	**Gap**	**r²**	**a**	**b**	
1	Alferes	7.59%	0.70	17.80	0.86	8.15%	0.77	11.79	0.92	0.56
2	Natividade da Serra	1.30%	0.71	10.06	0.99	1.85%	0.72	11.72	0.99	0.55
3	Redenção da Serra	0.78%	0.74	23.40	0.74	2.78%	0.77	23.32	0.75	2.00
4	Santa Branca 01	10.74 %	0.84	16.85	0.85	11.11%	0.88	11.29	0.92	0.36
5	Santa Branca 02	3.89%	0.80	21.75	0.78	4.81%	0.84	16.78	0.83	0.92
6	Igarata	1.67%	0.83	14.04	0.87	2.04%	0.85	14.05	0.88	0.37
7	Santa Isabel	5.00%	0.85	12.92	0.88	5.19%	0.86	13.60	0.88	0.19

Tabela 6: Unused Series Stations (Jan/1972 - Dec/2016).

Station	**Gap**	**r²**	**a**	**b**
Alto da Serra	5.22%	0.47	27.23	0.41
Bairro Alto	36.17%	0.76	35.89	0.81
Capuava	33.27%	0.75	20.92	0.91
Cedro	46.23%	0.79	28.67	0.86
Comércio	37.14%	0.86	16.70	0.92
Jardim	41.58%	0.82	24.19	0.66
Laranjal	33.46%	0.73	28.04	0.64
Paraibuna	35.98%	0.85	10.29	0.91
Paratei	29.98%	0.85	15.28	0.92
Pitas	51.45%	0.78	23.57	0.85
Represa - Monte Claro	35.20%	0.80	13.90	0.76
São José dos Campos	36.62%	0.81	19.13	0.88
Varadouro	47.39%	0.24	56.31	0.46

As a result of the treatment of the information, a continuous series of data for seven stations from January 1972 to December 2016 including 45 years (540 months) is conceived. These series are used to perform all the statistical analyzes.

3.2 Precipitation and Streamflow Anomalies

The SPI and SDI identify the years dry and wet extremes has occurred at the stations and measurement points located in the reservoirs (Figure 2).

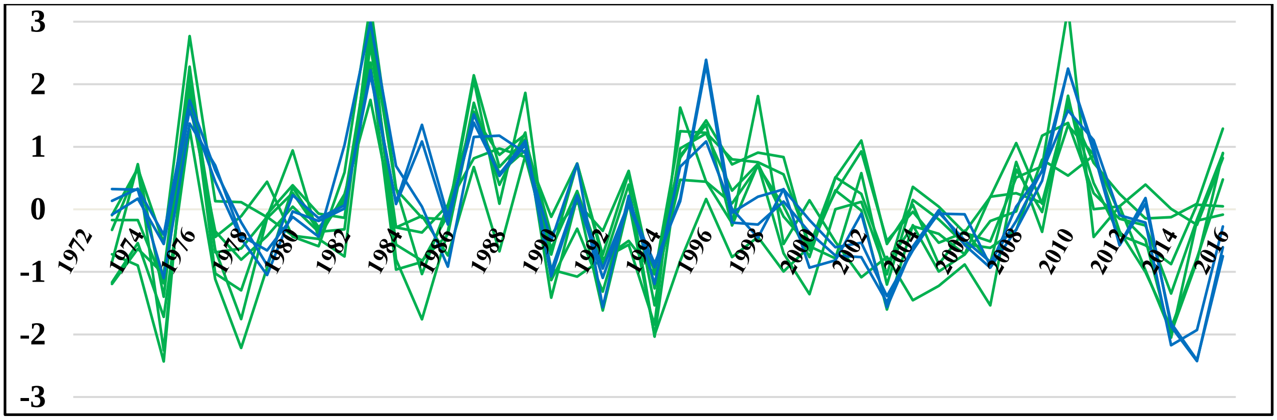

Figure 2: SPI (green) and SDI (blue) for all stations and reservoirs in the series (Jan / 1972-Dec / 2016).

The anomaly classifications are divided between dry and wet (Table 07 and 08). There are 79 precipitation anomalies among the seven stations, being 39 years dry and 40 wets. The dry occurrences classified as twenty-tree moderates, ten severe and six extremes. The wet occurrences classified as 16 moderates, 11 severe and 13 extremes. The occurrences present similar frequency. However, extreme and severe wet occurrences total 24 occurrences, representing 60 % of total wet occurrences. More than half of the stations presented dry anomalies in the years 1975, 1994 and 2014 and wet anomalies the years 1976, 1983, 1987, 1989, 1996 and 2010. The years of 1976 and 1983 all the seven stations have presented wet anomaly.

Table 7: SPI Wet Years (Jan./1972 – Dec./2016).

Stations	Extremely Humid	Severely Humid	Moderately Humid
Alferes	1976, 1983, 1987	1989, 2010	2016
Natividade da Serra	1976	1983, 1995, 1998, 2010	1987, 1989
Redenção da Serra	1976, 1983, 2010	-	1996
Santa Branca 01	1983, 1987	1976, 2010	1989, 2002
Santa Branca 02	1983	1987	1976, 1995, 1996, 2008, 2010
Igaratá	1976, 1983	-	1996
Santa Isabel	1983	1976, 1987	1989, 1996, 2009, 2010

Table 8: SPI Dry Years (Jan./1972 – Dec./2016).

Stations	Extremely Dry	Severely Dry	Moderately Dry
Alferes	1994	-	1975, 1977, 1978, 1990, 1992
Natividade da Serra	-	1994, 2007	1991, 2002, 2004, 2005
Redenção da Serra	1994	-	1973, 1975, 2000, 2003
Santa Branca 01	1975	1978, 2014	1994
Santa Branca 02	1978	1975, 2014	1973, 1977, 1994, 2013
Igaratá	1975, 2014	1994	1985, 2003
Santa Isabel	-	1985, 1992, 2003	1975, 1990, 2014

In the streamflow series, 37 years identify anomalies among the three measurement points, being fifteen dry and twenty-two wets (Table 09 and 10). The dry years show seven moderates, five severe and three extremes, and the wet years eleven moderates, four severe and 3 extremes. The wet events are more frequent than the dry ones. The extreme and severe years represent 50% of wet occurrences. All the stations present dry anomalies in the years 2003, 2014 and 2015 and wet anomalies in the years 1976, 1983, 1987, 1996 and 2010.

Table 9: SDI Wet Years (Jan./1972 – Dec./2016).

Reservoirs	Extremely Humid	Severely Humid	Moderately Humid
Paraibuna	1983, 1996, 2010	1976	1985, 1987, 1989
Santa Branca	1983, 1996, 2010	1976, 1987	1985, 1989
Jaguari	1983	2010	1976, 1982, 1987, 1988, 1996, 2011

Table 10: SDI Dry Years (Jan./1972 – Dec./2016).

Reservoirs	Extremely Dry	Severely Dry	Moderately Dry
Paraibuna	2015	2014	2003
Santa Branca	2015	2014	1979, 1990, 1992, 2003
Jaguari	2014	1992, 2003, 2015	1975, 1994

3.4 Correlation Analysis in the SPI and SDI Series.

The correlation results between the SDI and SPI can be verified in Table 11. The correlation between SDI 12 and SPI 12 for the hydrological year, SDI 6 and SPI 6 for the dry semester and SDI 3 and SPI 3 for rainy season presents r > 0.50, large correlation (COHEN 1988), for all the stations and measurement points. Jaguari reservoir has obtained r > 0.70 on all three scales. The correlations between SDI 6 and SPI 6 in the wet semester present r > 0.50 in all stations except Alferes (r = 0.46). Jaguari reservoir and the Igaratá station continue to present r > 0.70. SDI 3 and SPI 3, dry season, the correlation of all stations with the Paraibuna reservoir show r < 0.50, and the correlation between the Santa Branca reservoir and the Santa Branca 01 station also has not presented a large correlation. However, the Santa Branca reservoir and the Santa Branca 02 station and the Jaguari reservoir with its two stations present r > 0.50, which characterize a large correlation.

Table 11: SDI and SPI Correlation Analysis

SDI 12 x SPI 12 Hydrological Year	SDI 6 x SPI 6 Dry Semester	SDI 6 x SPI 6 Wet Semester	SDI 3 x SPI 3 Dry Season	SDI 3 x SPI 3 Rain Season
		Paraibuna x Alferes		
0.55	0.63	0.46	0.43	0.57
		Paraibuna x Natividade da Serra		
0.62	0.62	0.53	0.38	0.56
		Paraibuna x Redenção da Serra		
0.60	0.61	0.53	0.44	0.64
		Santa Branca x Santa Branca 01		
0.62	0.64	0.54	0.46	0.58
		Santa Branca x Santa Branca 02		
0.64	0.69	0.56	0.53	0.54
		Jaguari x Igaratá		
0.78	0.73	0.72	0.56	0.77
		Jaguari x Santa Isabel		
0.73	0.70	0.66	0.52	0.78

3.5 Observational Analysis of Results for Critical Years

Years with more representation are chosen in the annual scale analysis (Figure 03). SPI has been selected in the years in more than half of the stations presenting anomaly. The dry years are 1975, 1994 and 2014, and wet years are 1976, 1983, 1987, 1989, 1996 and 2010. SDI has been highlighted in the years with three points presented anomaly. The dry years are 2003, 2014 and 2015, and wet years are 1976, 1983, 1987, 1996 and 2010. Representative anomalies are observed for SPI and SDI concomitantly in the years 1976, 1983, 1987, 1996 and 2010 for negative (dry) anomalies and 2014 for positive (wet) anomalies.

The series can be divided into two parts: 1972 to 1993 and 1994 to 2016. The first half of the series presents years with a predominance of positive anomaly and the second half with negative anomaly. In the first half of the series most of the anomalies in general (positive and negative) occur in the dry semester and in the dry season. In the second half of the series there is an inversion and most of the anomalies generally have occurred in the wet semester and in the rainy season. Only the year 1975 presents these characteristics when analyzing the negative anomalies, in the first half. Positive anomalies are observed in the years 1976, 1983, 1987 and 1989. In the second half, there are predominant negative anomalies in 1994, 2003, 2014 and 2015. The positive anomalies are observed in the years 1996 and 2010. The occurrence of negative SDI in the wet and the rainy season in the first half of the series is not observed. Further to this, there is no occurrence of wet SPI in the dry semester and in the dry season in the second half of the series.

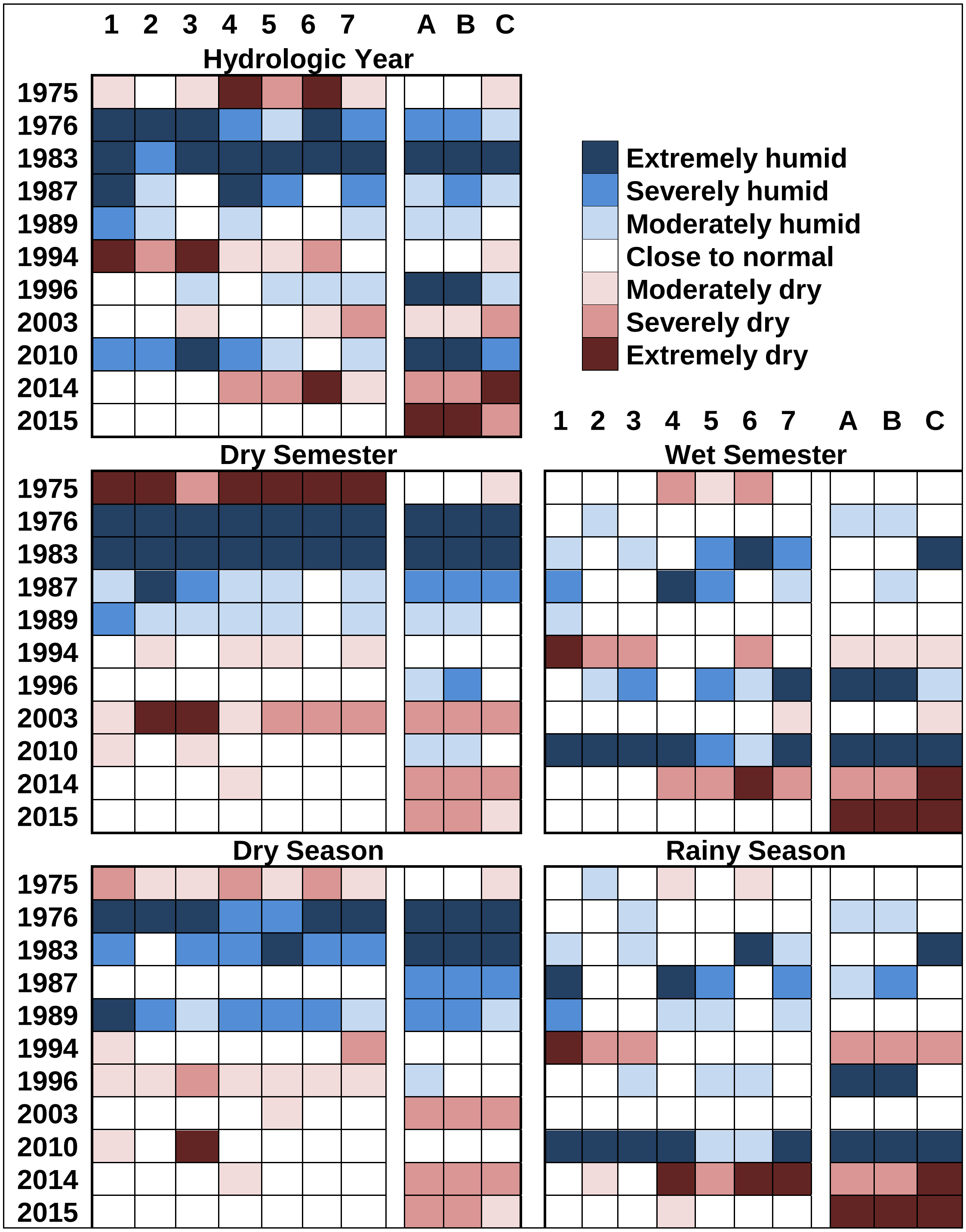

Figure 3: SPI and SDI representative years: (1) Alferes; (2) Natividade da Serra; (3) Redenção da Serra; (4) Santa Branca 01; (5) Santa Branca 02; (6) Igaratá; (7) Santa Isabel; (A) Paraibuna; (B) Santa Branca; (C) Jaguari.

4 Conclusions

The statistical treatments of the precipitation and streamflow series are necessary robust results. The analysis of quality and gapfilling is crucial to enable this research. The data base of ANA in a single system is an important resource. The complete series of natural streamflow, by the ONS, allows analysis with better comparison between the anomaly indexes.

Extremes of precipitation and streamflow can be observed in the spring of Paraíba do Sul watershed. Standardized index allows the comparison of precipitation and streamflow extremes. Cycles of about three to six years between the occurrence of extreme anomalies are observed. The extremes of precipitation and streamflow, in general, have a frequency relation in most of the years. However, regarding intensity, this relationship cannot be observed in all of the cases. Some years present extreme precipitation but regular streamflow. In other years the precipitation is regular and the streamflow extreme.

The study area has socioeconomic importance for the Southeast region. The analysis contributes for the facilitation of better planning of actions, reducing risks and strategies to mitigate the impacts of climatic extremes. This makes it possible to prepare users of the system for situations of extreme droughts and streamfloods. The identification of the periods, where the region becomes more susceptible to precipitation and streamflow, allows the decision makers to act efficiently to manage the hydraulic system.

This information enables the application of best practices at all levels of users and decision makers in the region. It is essential to improve the relationship between users and the available resource in order to achieve the level of development required for transition between traditional systems to sustainable system management. These actions allow the construction of management tools in line with the sustainable development model.

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