Drought characteristics for the south region of Brazil from 1983 to 2012: meteorological and hydrological approaches

An effective way to classify and evaluate droughts is the adjustment of hydrological series into drought indices. With this purpose, two different drought indices were applied to series of the South Region of Brazil, a location with the majority of hydrological studies not focused in low extremes. The Standardized Precipitation Index (SPI) and the Streamflow Drought Index (SDI) were applied for meteorological and hydrological analysis. The main focus of the study was to identify trends in these indices, and to analyze possible spatial patterns over the study area. From the results, it was verified the increase in drought severity in southern part of the study area, while decreasing trends were observed in eastern and northwestern parts. In the hydrological seasonal analysis, results have evidenced that in months with usually lower flows than the yearly average the rates are becoming even lower, while in months with higher flows the rates are increasing.

Keywords: Drought indices; Standardized Precipitation Index (SPI); Streamflow Drought Index (SDI).

Características das secas para a região sul do Brasil, entre 1983 e 2012: abordagens meteorológicas e hidrológica

Uma maneira efetiva de se classificar e avaliar secas consiste no ajuste de séries hidrológicas a índices de seca. Com esse propósito, dois diferentes índices de seca foram aplicados a séries da região Sul do Brasil, área em que a maior parte dos estudos hidrológicos não é direcionada a extremos hidrológicos mínimos. O Índice Padronizado de Precipitação (SPI) e o Índice de Seca de Vazões (SDI) foram aplicados como análises meteorológica e hidrológica. O foco principal do estudo foi identificar tendências para esses índices, além de analisar possíveis padrões espaciais para a área estudada. Com os resultados, foi verificado um aumento na severidade de secas na parte sul da área de estudo, enquanto tendências decrescentes de severidade foram observadas a leste e noroeste. Pela análise hidrológica sazonal, ficou evidenciado que em meses com vazões usualmente menores que a média anual, tais taxas vêm se tornando cada vez menores, enquanto para meses de vazão maiores as tendências se mostram positivas.

Palavras-chave: Índices de seca; Índice Padronizado de Precipitação (SPI); Índice de Seca de Vazões (SDI).

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INTRODUCTION

The extension and the effects of climate change in specific regions vary in space and time, requiring an individual and regular monitoring (HAJANI et al., 2018). The increase in the Earth's temperature affects the precipitation distribution, and according to IPCC (2013) regional temperature and precipitation may be physically related. Since climatic change affects significantly the global hydrological cycle, special attention should be given to extreme hydrological events, drought or flood events (TEEGAVARAPU et al., 2017).

Eslamian et al. (2017) point out that it is difficult to establish an ideal definition of a drought. Droughts initiate with a deficiency in precipitation over a region, resulting in diverse hydrologic consequences, as the decrease in soil moisture and low flows. However, these different implications may not occur simultaneously. Therefore, the drought phenomena shouldn't be considered as a single event, but as a variety of factors and approaches. Depending on the implications of the impacts, four main definitions of droughts are given: Meteorological drought, affecting precipitation; Agricultural drought, affecting soil moisture; Hydrologic drought, affecting groundwater and flows; and Socioeconomic drought, as the effect in society of the mentioned factors (TALLAKSEN et al., 2004).

Several different indices were developed for the characterization and classification of droughts over the years. Many of these indices, according to Yeh (2019), require the consideration of different types of data and a complex calculation. However, indices which consider one aspect of the drought, from meteorological, hydrological or agricultural, present an easier computation, using a reduced number of variables. Eslamian et al. (2017) raise that some indices are better adjusted to some specific climatological, topographical or temporal conditions, with these aspects being incorporated in the development of each of the indices. The World Meteorological Organization (WMO, 2016) states that the impacts of droughts may be as variate as the causes, and it is crucial its consideration in the establishment and selection of the study approach. Thus, the selection of an adequate drought index should also consider the appropriate data availability and its easiness of application.

The Standardized Precipitation Index (SPI) is a vastly used index for meteorological drought assessment. The index, created by McKee et al. (1993) requires only precipitation data, and is based on cumulative precipitation for different time scales, evaluating the divergence of the precipitation in the defined period compared to the long-term average. As a standardized index, studies regarding the SPI allow the comparison of results between different locations. The WMO recommends the SPI as the main index for meteorological drought monitoring, leading to numerous studies for locations worldwide (RAHMAT et al., 2015; DAS et al., 2015; JULIANI et al., 2017; BAYISSA et al., 2018; YEH, 2019).

With a similar methodology to the SPI, the Streamflow Drought Index (SDI) standardizes the hydrological variables of an event, describing severity and characteristics of hydrological droughts. Developed by Nalbantis et al. (2009), cumulative streamflow discharge is applied in different time scales for the analysis of variations in the severity of drought events. The SPI has been applied in different locations and climates, and is recommended for the hydrological drought assessment (ZAMANI et al., 2015;

MANIKANDAN et al., 2015).

Studies considering areas presenting humid climates mainly focus on flood extremes, thus these areas lack knowledge of droughts. The higher the awareness of the problem, the better is the competence in administrating the impacts of the phenomena, as water crisis, agricultural deficits and socioeconomic implications.

In this context, since climatic variables are subjected to processes of change in its patterns, a better understanding regarding its variability is important. Thus, the main objective of this paper is to evaluate trends in drought indices applied to the South Region in Brazil, analyzing two different approaches: meteorological and hydrological. The study targets the identification of regional patterns for the trends and also a spatialization of the results.

THEORETICAL REVIEW

The selected study area comprehends the South Region of Brazil, covering an extension of 576,743 km². The region is constituted by three federal units: Parana, Santa Catarina and Rio Grande do Sul, with annual average mean temperatures varying from 12°C and 24°C, and annual precipitation ranging from 1000 mm and 2200 mm, according to Alvares et al. (2013). Following the Koppen-Geiger classification, the predominant climate is the humid subtropical zone without dry season, majorly with hot summer, and a portion with temperate summer. As for a small parcel of the area at the extreme north and northeast of Parana, the classification points to a tropical zone with dry winter.

Figure 1: South region: sub-basins delimitation and selected stations.

According to the Brazilian Water National Agency (ANA), 49 hydrological sub-basins of second level are located within the South region, with nine of these dividing its drainage area with states of the Southeast and Center-West Regions. For this present study, two stations were selected in each one of these sub-basins

contained in the South Region: one pluviometric and one fluviometric. The data was obtained from the Hydrological Information System website - HidroWeb (ANA, 2020). This selection considered a spatial distribution and the data availability, with a minimum of 30 years of consisted monthly data. For the streamflow stations, the presence of reservoirs was also considered, as it influences the natural historical series.

Considering the adopted criteria, 12 sub-basins did not present stations with sufficient information for the study and were not evaluated. Thus, this paper will cover 37 sub-basins located in the South Region of Brazil. The delimitation of the adopted sub-basins and the location of the stations is presented in Figure 1. The areas excluded from the analysis are presented in Figure 1 as hatched areas. For comparison reasons, the same period of analysis was set for all the stations, defining series starting in 1983 and ending in 2012. The last year of the series was limited by the most recent year with validated streamflow data available in HidroWeb (ANA, 2020).

METHODOLOGY

In this paper, two different views for the drought phenomena are considered: meteorological and hydrological droughts. Therefore, two different drought indices were selected for evaluation: the Standardized Precipitation Index - SPI (MCKEE et al., 1993) analyses the drought from the meteorological perspective, while the Streamflow Drought Index - SDI (NALBANTIS et al., 2009) as an hydrological approach. The selection of the indices took into consideration the two distinct drought perspectives and the availability of hydrological records required. Both indices present similar methodologies and are validated by several studies over different locations. Thus, this study aims to evaluate both approaches and identify possible patterns in the South Region of Brazil.

Standardized Precipitation Index

In the development of the Standardized Precipitation Index (SPI), McKee et al. (1993) proposed a definition of drought based in a standardized precipitation, as the difference of observed value related to the mean average of the period, divided by the standard deviation. This calculation results in a linear standardized value equivalent to the precipitation deficit, allowing the specification of probabilities and cumulative deficits.

The methodology of the SPI initiates with the selection of a precipitation monthly series, ideally with a minimum 30 years of records. A time scale should be adopted for the moving average computation, representing typical deficit periods as 3, 6, 12, 24 or 48 months. From this, a new series with the moving averages representing the average of the previous i months is generated (MCKEE et al., 1993).

The next step is the adjustment of the new series to a statistical distribution, for a better definition on the probability relations. Okpara et al. (2015) states that this adjustment should consider a statistical distribution with a good fit for the series evaluated. As the SPI applies a methodology based on precipitation, the Gamma distribution is assumed to present a good fit in a monthly scale for these data, as it is limited by

zero. This analysis is verified by the studies in different locations: state of Minas Gerais, Brazil (JULIANI et al., 2017); Ethiopia (BAYISSA et al., 2018); Australia (RAHMAT et al., 2015); Germany and the Netherlands (KUMAR et al., 2016); among others.

The adjustment of the data to the Gamma probability density is demonstrated in Equation 1. The parameters α , β and x are positive values representing shape, scale and the cumulative precipitation.

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad (1)$$

The shape and scale parameters have different estimations, as the Maximum Likelihood Estimation method (THOM, 1958), described in equations 2, 3 and 4. Equation 3 represents the difference between the logarithm of arithmetic and geometric averages.

$$\hat{\alpha} = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right) \quad (2)$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad (3)$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \quad (4)$$

The cumulative Gamma distribution may be expressed by the integration of the Gamma probability density function. Substituting $t = x/\beta$, the cumulative distribution is given in Equation 5.

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-t} dt \quad (5)$$

Finally, the Gamma function for the distribution may be computed as Equation 6.

$$\Gamma(\alpha) = \int_0^\infty x^{\alpha-1} e^{-x} \quad (6)$$

Based on the cumulative probabilities of the Gamma distribution ($G(x)$) applied to the series of moving averages, the probabilities are fitted to a Normal distribution, with a mean of zero and variance equals of one, thus standardizing the initial series as the representation of the SPI. The SPI can be summarized by Equation 7.

$$SPI = \psi^{-1}[G(x)] \quad (7)$$

The standardized index allows the identification of wet and dry periods, and both are classified according to the varying intensity in the categories: Normal, Moderate, Severe and Extreme. Normal periods represent SPI values near the average, while the extreme classification refers to the most outlying values. The SPI classification may be stated as Table 1.

Table 1: SPI Classification for wet and dry periods.

Category	SPI
Extremely wet	$\geq 2,00$
Very wet	1,50 a 1,99
Moderately wet	1,00 a 1,49
Near normal	-0,99 a 0,99
Moderate drought	-1,49 a -1,00
Severe drought	-1,99 a -1,50
Extreme drought	$\leq -2,00$

Font: Eslamian et al. (2017).

Streamflow Drought Index

In the conception of the Streamflow Drought Index (SDI), Nalbantis et al. (2009) took into consideration a temporal analysis of the existing hydrological processes, as streamflows are highly affected by seasonal variants. Thus, the application of this hydrological index contemplates the division of the year in four periods of analysis. The selection of these periods should consider the hydrological year for the specific location of analysis.

The application of the SDI requires a monthly historical flow data series with at least 30 years available (OZKAYA et al., 2019). The monthly averages $Q_{i,j}$ are defined by the hydrological year i and by the month j . For the summarization into the four different periods, defined as k , the Equation 8 is applied.

$$V_{i,k} = \sum_{j=3k-2}^{3k} Q_{i,j} \quad i = 1, 2, \dots \quad j = 1, 2, \dots, 12 \quad k = 1, 2, 3, 4 \quad (8)$$

Each of the series of $V_{i,k}$ is then adjusted to a log-Normal distribution of two parameters, considered a statistical distribution with a good adjustment to the series by Nalbantis et al. (2009), as described in Equation 9. Equation 10, then, presents the calculation of the SDI series for each station.

$$y_{i,k} = \ln(V_{i,k}) \quad i = 1, 2, \dots \quad k = 1, 2, 3, 4 \quad (9)$$

$$SDI_{i,k} = \frac{y_{i,k} - \bar{y}_k}{s_{y,k}} \quad i = 1, 2, \dots \quad k = 1, 2, 3, 4 \quad (10)$$

Trend Tests

Adjusted the drought indices to the selected stations, 37 historical series of each of the indices were obtained. The next step of the study was the application of linear trend tests to these series. The linear trends were tested by the Mann-Kendall test (MANN, 1945; KENDALL, 1975) and by Theil-Sen Estimator (THEIL, 1950; SEN, 1968).

RESULTS AND DISCUSSION

The historical records of precipitation and streamflow for the previously listed stations were adapted to the application of the drought indices mentioned: Standardized Precipitation Index (SPI) and Streamflow Drought Index (SDI). This way two new series were derived from each studied sub-basin, corresponding each of the drought indices. To these series the Mann-Kendall test and Theil-Sen estimator were then applied for linear trend identification.

Tests applied to the Standardized Precipitation Index

Applied the Mann-Kendall test to the Standardized Precipitation Index series of the 37 studied points, a mixed result with positive, negative and non-significative trends were identified. Six of the stations presented a positive trend for the SPI, while 11 stations registered a negative trend for the index. The test did not point out trends at a 5% significance level for the remaining 20 stations. It must be highlighted that for a rejection of the null hypothesis of stationarity at a 5% significance level, the registered p-value must be smaller than 0.05, indicating a non-stationary series, with the existence of a positive or negative trend.

It was verified a concentration of negative trends identified by the Mann Kendall test mainly in Rio Grande do Sul state. From this, it can be inferred that in the most recent years the drought events are becoming more severe in the south of the study area, since negative trends represent lower indices for the recent years, and as lower the index is in scale, more severe is the drought event. It can also be noted another station with a negative trend, Porto Vitoria, distanced from the others. These trends were evidenced at a 5% significance level. The greater reduction in the index, evidenced by the greatest Theil-Sen coefficient, was identified for Passo do Novo station, in sub-basin 263, and this reduction is demonstrated in Figure 2.

Figure 2: Linear trends for the Standardized Precipitation Index.

Analyzing the results with the rejection of the null hypothesis with positive trends, these stations couldn't be clustered in the same small area, as the ones with negative trends. A group of these stations was identified in eastern Parana and in northeastern Santa Catarina, and also two stations in the northwest of Parana. The other station with a positive SPI trend was Saudades, in sub-basin 265, and this linear positive trend is showed in Figure 2.

Figure 3: Meteorological drought trend indicators for the South Region.

From the obtained results, it was observed that even in the SPI series with a Mann-Kendall p-value greater than 0.05, the results from the Theil-Sen estimator indicated possible trends. Thus, increases and

decreases in the SPI were demonstrated by the Theil-Sen estimator, although these shifts are less intense than the ones from series with smaller SPI Mann-Kendall p-values. The series of SPI from Ibirama, sub-basin 79, and Rio Varzea dos Lima, sub-basin 74, are two examples of this case.

Taking into consideration the subjectivity related to the existence or not of a trend based only in the Mann-Kendall p-value, the series with p-values higher than 0.05 and with an existing Theil-Sen estimator coefficient were classified with “no significative trend”, and the location of these stations is showed in Figure 3, along with the stations with significative results at a 5% level.

From the locations of the stations with no significative trends it was verified the dominance of negative trends in the south of the study area, comprehending the inner part of Rio Grande do Sul state, excepting sub-basins 127 and 216. As the Standardized Precipitation Index is a meteorological drought index, it can be assumed that this state, in general, presents in most recent years a greater number of severe meteorological drought events than in the first studied years.

In contrast, the stations situated in the east, along the coastline, presented an increase in SPI values. This indicates a reduction in the magnitude of severe drought events in the most recent years in these locations. This fact is also applied for sub-basins 27 and 265, and also for the northwest of Parana.

Spatial analysis of the Standardized Precipitation Index

Figure 4: Spatial distribution of the SPI for the South Region in the years 1985, 1990 and 1995.

Following the localization of the stations for the Standardized Precipitation Index, it is possible to obtain an interpolation map for the visualization of the result in points where a local analysis was not performed. Thus, from the results of the index in a specific date for all the stations, it is possible to obtain the spatial behavior of the drought phenomena. In this paper, for comparison reasons, the spatial plot was tested for summer (January) and winter (July) periods, in 5-year intervals, to check if the regional influence

of these events has changed over the years. These maps are shown in Figures 4 and 5.

Figure 5: Spatial distribution of the SPI for the South Region in the years 2000, 2005 and 2010.

For the year 1985 it is possible to observe the predominance of a moderate drought for almost the whole area of the South region in summer, while in winter the difference between regions with droughts from moderate to extreme in the north portion and regions with the predominance of moderate and severe rains in the south portion.

For the year of 1990, it can be observed in the summer some moderate and severe wet events in the center-north area of study, and an intensification of an extreme drought event in the south. In winter the situation was reversed when compared to the year of 1985, with the north portion of the study area presenting a wet situation and the south portion with some cases of drought, with a few extreme indices.

In the summer of 1995, it can be observed the predominance in the study area of a wet situation, even with some severe indices in the northeast of the area and with the presence of moderate droughts in the south. For the winter of this year, once more the duality between north and south of the study area can be noted, with the north portion presenting drought areas, and the south portion with the predominance of rains. For this period, both wet and drought indices were classified as moderate.

The year of 2000 registered an increase in the affected area by moderate and severe droughts in summer. As for the winter period, most part of the study area presented normal indices, with some moderate drought indices found in the east of the state of Santa Catarina, and some moderate rains in north of Parana state.

The summer of 2005 registered moderate and extreme drought indices for almost the whole South region, this being the most extensive drought observed from the evaluated years, and also the most severe indices calculated. In winter, for the whole area in general, it can be found some punctual moderate events of droughts and rains.

For the summer of 2010, the predominance in the South region is for the occurrence of moderate rains, with some punctual severe rains and moderate droughts. In the winter of this year, once again the contrast between the north and south parts of the study area is visualized, with Parana state presenting droughts and Rio Grande do Sul state presenting wet events. For this winter, the events found were classified as moderate.

With the spatial distribution of the Standardized Precipitation index, it was possible to visualize the variation of the events along the years, from the changing in spatial patterns and also from the change in the severity pointed out by the indices for the different years. It was also possible to observe the spatiality and the regional influences of the drought phenomena, once the patterns were easily identified, confirming the fact that meteorological droughts, that are based on precipitation, do not present punctual events, but spatial distributed effects.

Related to the differences noted inside the South region, the main point was the divergence of the indices for the winter periods. A high contrast of the indices was found between the north and the south of the study area.

Tests applied to the Streamflow Drought Index

The fit of the Streamflow Drought Index (SDI) is divided according to the seasonality of the hydrological year for the study area. However, for the South region of Brazil the hydrological scheme is considered erratic, without a defined seasonality. By this reason, for the application of the SDI, the division of the four periods considered the trimestral division of the civil calendar: January - March, April - June, July - September and October - December. The index was applied for the fluviometric stations of the 37 studied sub-basins, taking into consideration seasonal periods of three months. Therefore, the SDI series are composed by 30 data points, as annual series for each of the analyzed periods, and not as a monthly series as for the Standardized Precipitation Index.

Applied the Mann-Kendall test to the four series of the Streamflow Drought Index for each of the studied stations, the results were evaluated at a 5% significance level, rejecting the stationarity hypothesis in the cases where the p-value was smaller than 0.05.

For the first period analyzed, from January to March, two stations were identified with positive trends at a 5% significance level by the Mann-Kendall test: Ipiranga - sub-basin 67, and Fazendinha - sub-basin 70. For the other stations, it was not identified at a 5% significance level statistical trend, and therefore, the series were considered stationaries for the 30-year period analyzed.

For the period from April to June, negative trends at a 5% significance level were identified for 16 of the studied stations, associated to the following sub-basins: 26, 66, 73, 76, 86, 88, 126, 190, 201, 210, 216, 237, 262, 263, 264 and 266.

The Mann-Kendall test applied to the SDI series of the third period, from July to September, identified three stations with a negative trend for the index at a 5% significance level: Conceição - sub-basin 76; Dona Francisca - sub-basin 88; and Tucunduva - sub-basin 262. It is worth highlighting that these three stations

also presented statistically negative trends in the SDI for the period from April to June.

Lastly, for the period from October to December, the null hypothesis of stationarity was rejected for only one of the SDI series at a 5% significance level, according to the Mann-Kendall result. It should be also pointed out that this station also presented a positive trend for the period from January to March.

It is important to note the differences from the trends of SPI and SDI. The trends from the second index were more accentuated than the ones verified for the SPI.

A new map was plotted with the location of the hydrological stations, as shown in Figure 6, and it is possible to visualize the predominance of the negative trends in the inner part of Rio Grande do Sul and in the west of Parana. The two stations which have presented positive trends at a 5% significance level are geographically apart from each other, and the locations represent the capitals of the states Parana and Rio Grande do Sul.

Figure 6: Hydrological drought trend indicators for the South Region.

However, as explained for the SPI series, the Mann-Kendall results were evaluated at a 5% statistical significance level. The series which result did not match this significance level may still present a trend, even if the test rejects it. Thus, the results obtained by the Theil-Sen estimator were evaluated for the four periods of the Streamflow Drought Index.

Evaluating the set of the four periods for the same stations, for some stations the trend results were distinct, as for Ponte do Vitorino - sub-basin 72. For this sub-basin, by the Theil-Sen estimator it could be verified a decrease in the SDI rates in the first three periods, while the series from October to December was identified with an increase for the index. Cases such as the station Ponte do Vitorino validate the existing seasonality of flows, as the SDI is calculated based on fluviometric series. This fact supports the seasonal application of the index. Therefore, for a single station different SDI trends may be identified, according to the period of the year.

In the periods from January to March and from July to September, positive trends can be attributed

for a group of stations located in center-east of Parana, and also for stations located in the east of the entire study area. The higher concentration of stations with negative SDI trends is located in Rio Grande do Sul state.

The major outcome of the SDI analysis, however, is in the fact that for the period from April to June, almost the totality of the studied stations have presented a negative SDI trend, with the exceptions for the stations Fazendinha - sub-basin 70, Morretes - sub-basin 119, and Major Gercino - sub-basin 129. These listed stations have presented ascending trends for the four SDI series. On the opposite way, for the period from October to December, 33 of the 37 stations have presented descending SDI rates, implying in less intense drought events for this period in the most recent years.

These findings are important, once it demonstrates that in regular low flow months, as from April to June, the drought events are becoming even more severe, while in months where the flow rates are usually bigger, as from October to December, the opposite occurs.

CONCLUSIONS

It is notorious the impact of droughts in society, affecting the environment and also the economy. As a phenomenon basically influenced by hydrological variables, the knowledge regarding its behavior is fundamental to a better comprehension about how these events work.

The drought indices facilitate the quantification of the impacts of the occurrences of droughts along a certain period. Among the several existing indices, for this study it was selected the Standardized Precipitation Index and the Streamflow Drought Index. Both indices had an appropriate application, using precipitation data for the first and flow data for the second.

The Standardized Precipitation Index provides an easier identification of meteorological droughts, related to rainfall deficits. By the spatial application of the index in South region of Brazil, it was possible to identify regional patterns, especially in winter periods, with a notorious difference between the indices in the south and in the north of the study area. It also became evident to be a changeable process either spatially and temporally.

Regarding the spatialization of the linear trends of the SPI series, the stations may be divided into two groups. In the south, in nearly the entire Rio Grande do Sul state, negative trends are verified for the index, indicating an increase in drought severity for the most recent years. As for east portion of the study area, near coastal areas of all South region, and also in northwest Parana, positive trends were identified.

The application of the Streamflow Drought Index was performed for four different periods of the year, considering the existing seasonality of flows. As the results are related to a specific flow at a determined river, influenced not only by its catchment area, but also by topography and other parameters, a spatial interpolation could not be outlined with the punctual results.

As for the application of the Mann-Kendall test to the SDI series, the obtained results at a 5% significance level pointed to a higher amount of negative trends in the periods of winter, and positive trends for the summer months. This is an important result, as it demonstrates that in months when flows are usually

lower in an annual scale the rates in recent years are becoming even smaller, while for months with higher flow rates the trends pointed to an increase of humid events.

With the identification of trends for both indices, it can be implied a shift in patterns of both hydrological variables: precipitation and flow. The changes regarding low flow rates may be related to anthropic activities and also to changes in precipitation. However, as changes were also identified in the series regarding precipitation, it can be implied that climatic changes are affecting the hydrological phenomena, affecting atmospheric and temperature patterns that influence the drought and humid events explored in this paper.

Coherent spatial results were found between SDI and SDI trends, mainly in Rio Grande do Sul state and in sub-basins located in the east of the study area. However, a difference between the two indices was the steeper trends of the SDI when compared to the ones of the SPI. The series of SPI do not consider the natural seasonality of the hydrological year, soothing the trend results. This seasonality is not important when analyzing the meteorological impacts of the drought, once these impacts are translated over periods by the hydroclimatological variables. For this study, it was applied historical series from 1983 to 2012. When analyzing different periods, with the inclusion of new data, the verified trends may present variations.

As recommendation for future studies, there is a possibility for the application of the indices in a larger number of stations, providing a wider spatial analysis. Moreover, studies with longer time series and with more recent data may present different results, so a continuous monitoring would bring a better understanding in the variability of the indices.

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