XXIV SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS

ASSESSMENT OF THE EFFECTS OF HYDROLOGICAL DROUGHT PERIODS ON SEVEN BRAZILIAN RESERVOIRS

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RESUMO: Eventos de estiagem vem ocorrendo em várias regiões do Brasil, com impactos nos sistemas de abastecimento. A quantificação da intensidade da estiagem e a avaliação do potencial efeito na dinâmica térmica dos reservatórios são assuntos que demandam maior atenção, devido aos cenários que preveem aumento na frequência desses eventos. Os objetivos deste trabalho são: aplicar dois índices para caracterizar os períodos de estiagem em sete reservatórios do Brasil, bem como discutir os resultados preliminares desses eventos de estiagem na dinâmica térmica desses reservatórios. Os reservatórios se localizam nas regiões Sul, Sudeste e Centro-Oeste do Brasil. Foram calculados dois índices de estiagem: o índice padronizado de precipitação (SPI) e o índice padronizado de precipitação e evapotranspiração (SPEI). Os resultados dos índices de estiagem foram avaliados em conjunto com os dados de volume dos reservatórios. Além disso, foram calculados índices físicos dos reservatórios, com resultados de simulação ou medição, para avaliar os efeitos da estiagem na dinâmica térmica dos reservatórios. Os períodos identificados pelos índices de estiagem estão relacionados aos períodos de redução de volume dos reservatórios, porém as características de operação e a existência de reservatórios em cascata são fatores importantes para a interpretação das variações de volume. Com os eventos de estiagem houve tendência de aumento da diferença de temperatura entre a superfície e o fundo para quatro dos reservatórios estudados. No entanto, outras

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variáveis podem estar influenciando os resultados e devem ser estudadas com maior detalhe em trabalhos posteriores.
Palavras chave – dinâmica térmica, estiagem, reservatórios

ABSTRACT: Drought events have been occurring in several Brazilian's regions with impacts on water supply systems. Studies that quantify drought intensity and assess the potential effects on thermal dynamics of reservoirs should be carried out, since future scenarios forecast an increase of such events. This work intends to apply two drought indices to characterize the drought periods in seven reservoirs of Brazil, as well as to discuss the preliminary results of these drought events on the thermal dynamics of the reservoirs. The reservoirs are placed in South, Southwest and Midwest regions of Brazil. Two drought indices were applied: Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI). The results of the drought indices were assessed in tandem with the volume data of the reservoirs. Moreover, physical indices of reservoirs were computed to assess the effects of drought periods on the thermal dynamics of the reservoirs. The periods that were identified by the drought indices are related with the periods of reduction of the reservoirs' volume. However, the operation characteristics and the existence of cascade reservoirs played a role on the interpretation of volume variation. During the drought periods there was a tendency of increase of the temperature difference between the surface and the bottom on four reservoirs studied. Other variables may nevertheless influence the results and should be considered in more detail on future research.
Keywords – drought, reservoirs, thermal dynamics

INTRODUCTION

The intensity and variability of extreme climatic events, such as floods and droughts, are projected to increase worldwide, affecting the hydrological cycle and ultimately the water supply (Kundzewicz et al. 2007). The ongoing climatic changes reveal several challenges to interpret limnological results (Read et al. 2014), as well as to predict water quality alterations and to investigate strategies of reservoir operation (Gelda et al. 2019). These issues gain particular relevance to water supply reservoirs. Droughts are often associated with low precipitation rates, higher incident radiation and air temperatures, along with elevated pressure from consumptive users. These meteorological conditions may lead to greater algal biomass growth in reservoirs, as the reduced depths also favor the proliferation of cyanobacteria (Baldwin et al. 2008; Havens et al. 2019). Since the frequency and severity of droughts are expected to intensify in the future (Dai 2013; Trenberth et al. 2014), planning and mitigation actions should be especially based on reservoir monitoring and impacts assessment (Cunha et al. 2019).

In Brazil, large freshwater resources are irregularly distributed at both temporal and spatial domains, which affects their availability and quality in different regions (ANA, 2019). Southeast Brazil faced a drought period between 2014 and 2015, which led to a crisis in the water supply system in the São Paulo metropolitan region affecting more than 8 million people (Cunha et al. 2019). Belo Horizonte metropolitan region also experienced a water supply crisis due to the drought in the same period (Soares et al. 2019). Brazil's Midwest region suffered from drought periods, in 2016 and 2017, which resulted in intermittent water supply to different subsystems, reduced pressure in the water system and water usage restrictions (ANA 2017; Lima *et al*. 2018). Due to the increasing water consumption over the last decades, water losses in the distribution network and low precipitation indices Brasília suffered a water crisis. Its supply reservoirs, Descoberto and Santa Maria, reached critical levels. Because of this, Paranoá Lake started being used as a water supply reservoir. More recently, the Brazilian Southern is experiencing an extremely severe drought, which led the creation of a Crisis Committee by the *Agência Nacional de Águas e Saneamento Básico* (ANA) [National Water and Sanitation Agency], in March 2020, to deal with water scarcity in this region of country. Paraná, specifically, has been in a water emergency since May 2020, with the adoption of water rationing measures (PARANÁ, 2020; PARANÁ, 2021).

To quantify the intensity of drought periods and evaluate the potential effects on reservoirs' thermal dynamics has become a critical point to water management. The goals of this study are to apply two drought indices for appraisal of drought characteristics in seven Brazilian reservoirs, and to discuss preliminary results of drought periods on reservoirs thermal dynamics, using a process-based hydrodynamic model.

MATERIAL AND METHODS

Study sites

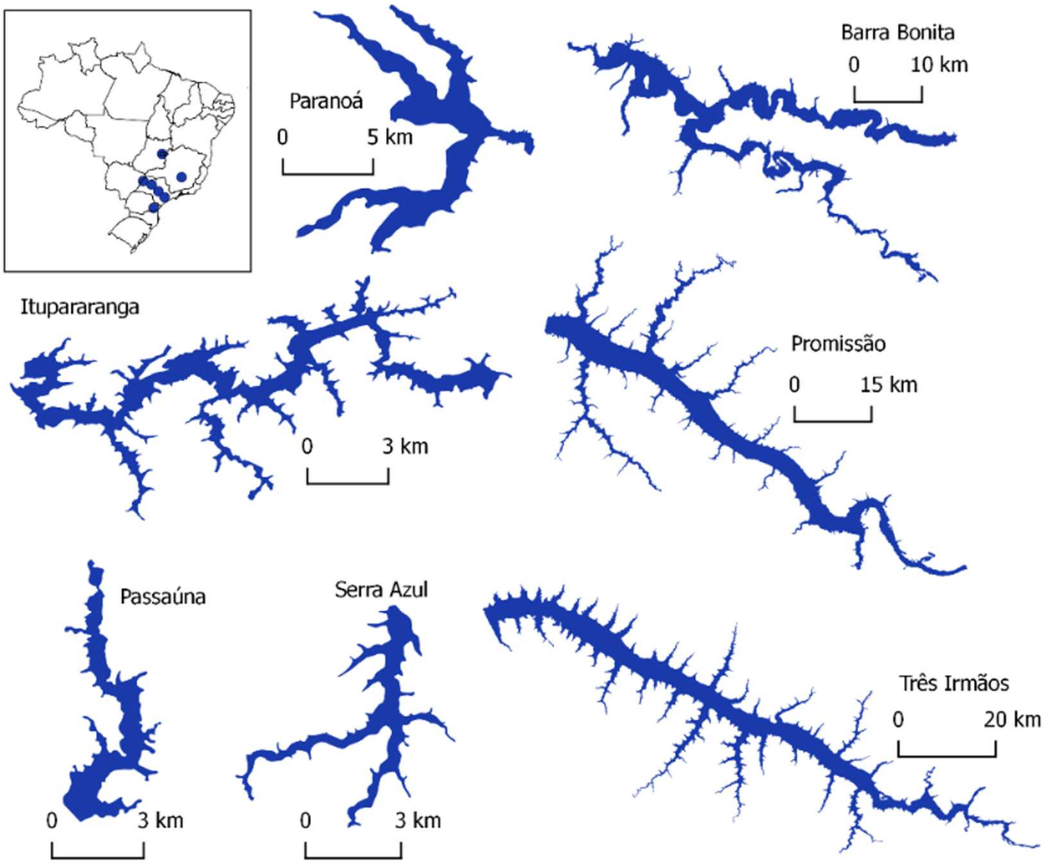
Seven reservoirs were selected for the present study (Figure 1) based on the following conditions: (i) bathymetrical, hydrological and meteorological data availability and reliability for model input; (ii) in-situ water level and temperature measurements available for model calibration and validation; and (iii) a drought event over the simulation period. The reservoirs attend either water supply and/or hydropower generation. They are located under different climate conditions and present a varied range of morphometric features and thermal regimes (Table 1).

Table 1 - Characteristics of the reservoirs.

Reservoir	Location[1]	Climate[2]	Main use[3]	Max. depth (m)	Surface area (10^6 m²)	Total volume (10^6 m³)	Residence time (days)	Thermal regime
Passaúna	PR	Cfb	WS	16.5	9.0	59	292	Polymictic
Itupararanga	SP	Cwa	WS, HP	23.0	29.0	286	245	Polymictic
Barra Bonita	SP	Cwa	HP	23.5	226	300	91	Polymictic
Promissão	SP	Cwa	HP	24.5	522	800	141	Warm monomictic
Três Irmãos	SP	Cwa	HP	45.6	654	11000	442	Warm monomictic
Serra Azul	MG	Cwa	WS	47.3	9.11	80	373	Warm monomictic
Paranoá	DF	Aw	WS, HP	38.0	37.5	498	299	Warm monomictic

[1]PR: Paraná; SP: São Paulo; DF: Distrito Federal; MG: Minas Gerais. [2]Koppen (1948). Cfb: Temperate oceanic; Cfa: Humid subtropical; Aw: Tropical savanna; Cwa: Dry-winter humid subtropical. [3]WS: Drinking water supply; HP: Hydropower generation.

Figure 1 - Study sites location and reservoirs shapes. Each reservoir is presented in a different scale for visualization.



Drought indices

Drought indices were applied as a first approach to identify the drought periods and to quantify the intensity of these events in the region of each reservoir. Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) were selected because they are widely applied and well established in the literature (McKee et al. 1993; WMO, 2016). A drought event is considered as a period in which the SPI is continuously negative and reaches a value of -1.0 or less (McKee et al. 1993).

According to the World Meteorological Organization (2016), SPI is a starting point for drought monitoring and SPEI is calculated in a similar way, but with a temperature component. Both indices were computed using the R package SPEI (Beguería and Vicente-Serrano, 2017). The Thornthwaite equation was chosen to compute the potential evapotranspiration, which is used for SPEI calculation. Both indices were computed at a timescale of 12 months. There are other options of timescale (for example, 3 and 6 months), but to evaluate hydrological impacts a timescale of 12 months or longer is recommended (WMO, 2016).

Meteorological data used to calculate SPI and SPEI indices includes monthly total precipitation and monthly mean air temperature. These data were obtained from different stations situated as close as possible to the studied reservoirs (Table 2).

Table 2 - Meteorological stations and data time period.

Reservoir	Meteorological Station (code and name - INMET)	Altitude (masl)	Latitude and Longitude (Datum WGS-84)	Time period
Passaúna	83842 – Curitiba	923.50	−25.448611, −49.230555	01/1990 - 01/2021
Itupararanga	83851 – Sorocaba	598.00	−23.483056, −47.426389	09/2006 - 12/2018
Barra Bonita	A741 – Barra Bonita	533.68	−22.471111, −48.557500	04/2008 - 05/2021
Promissão	A735 – José Bonifácio	408.35	−21.085675, −49.920388	09/2007 - 05/2021
Três Irmãos	A704 – Três Lagoas	328.94	−20.783333, −51.712222	09/2001 - 05/2021
Serra Azul	A535 – Florestal	753.50	−19.885398, −44.416883	06/2008 - 05/2021
Paranoá	A001 – Brasília	1160.96	−15.789343, −47.925756	01/1990 - 03/2021

Hydrodynamic simulations

The General Lake Model (GLM) was used for simulating water balance and vertical stratification in reservoirs. GLM is a one-dimensional hydrodynamic model, freely available (Hipsey et al. 2019). The 1D model computes the temperature, salinity, and density gradients in vertical profiles, for a horizontal layered lake structure, considering the effect of hydrological and meteorological forcing (Hipsey et al. 2019).

Time-series of hydrological and meteorological data, reservoirs bathymetry, and water temperature and salinity in the inflows were used as input data for the hydrodynamic simulations. Those data were provided by the energy, water utility companies and governmental agencies (INMET, 2021; ANA, 2020). All model setups have been calibrated against measured water levels and temperature profiles. More detailed information on the model setup and calibration for each reservoir can be found in Barbosa et al. (2021), Soares et al. (2019), and Sales (2020).

Effects on reservoir storage volume and thermal dynamics

The storage volume of the reservoirs was evaluated through descriptive statistics, according to available operation data (Passaúna and Paranoá reservoirs) and simulation results for the others. Paranoá data was provided by CAESB (Environmental Sanitation Company of Federal District) and it comprises measures of temperature once a month in six depths, from 2001 to 2017.

The analysis of the drought effects on the reservoirs' thermal dynamics were carried out by computing physical indices for each reservoir along the simulation period or using available field measures in the case of Paranoá reservoir. Lake Analyzer open-source software, developed by Read et al. (2011), was used. The package rLakeAnalyzer (Winslow et al. 2018) was applied to assess the effects of drought periods on the reservoir's hydrodynamics.

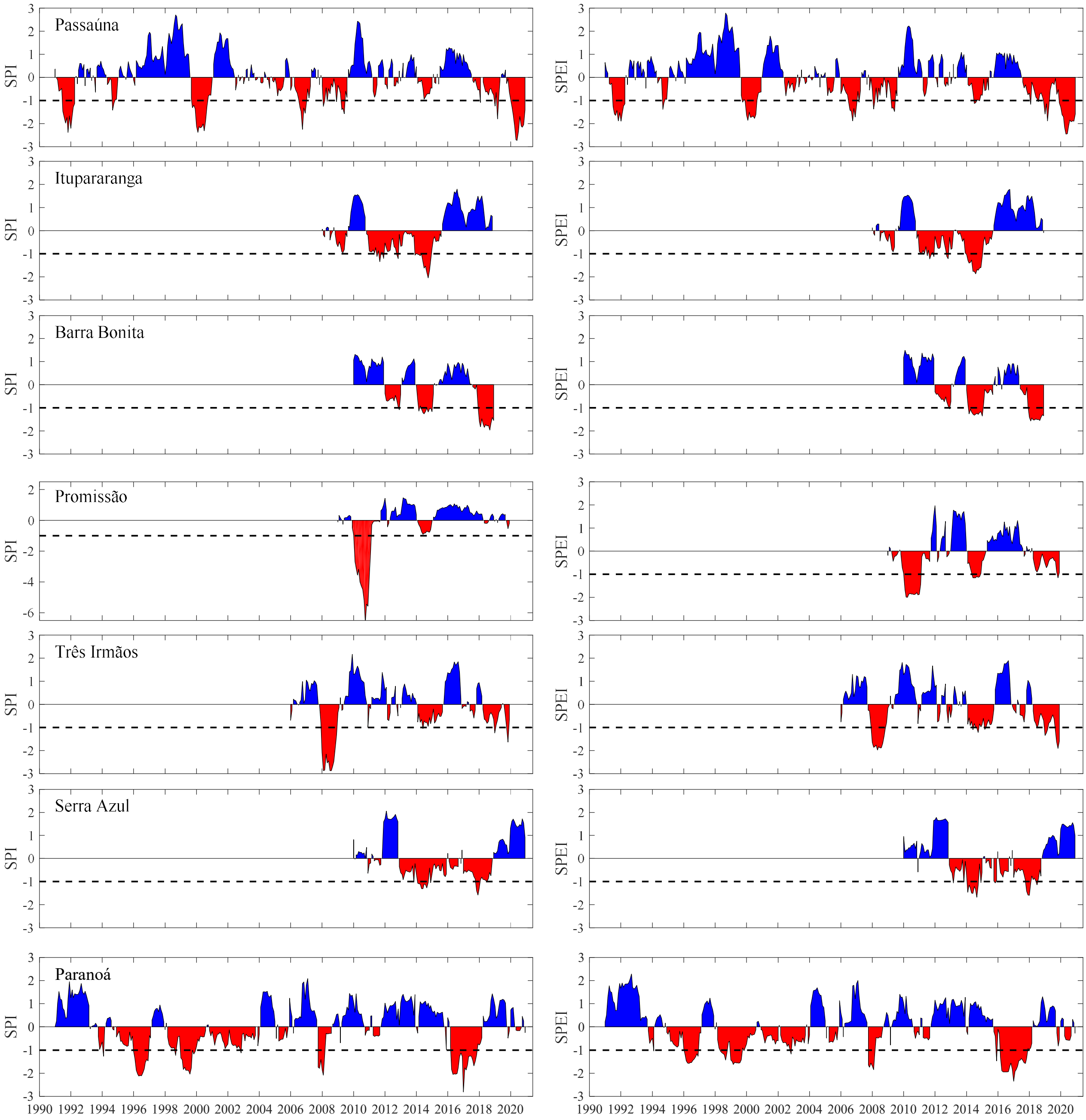
The physical index presented in this study was the difference between surface and bottom water temperatures. These results were compared between periods of different drought intensity, following the McKee et al. (1993) classification.

RESULTS AND DISCUSSION

Assessment of drought periods

Both SPI and SPEI indices revealed the same drought periods faced by each reservoir over the time series with available data in each meteorological station (Figure 2). While the Paranoá, Promissão, and Três Irmãos reservoirs showed lower SPEI than SPI values, Serra Azul and Barra Bonita reservoirs presented an inverse result, which may indicate the major influence of evaporation processes in these reservoirs.

Figure 2 - Standardized Precipitation Index (SPI) and Standardized Precipitation and Evapotranspiration Index (SPEI) in each reservoir.



All reservoirs presented a higher number of days with SPI above -1. Most of them showed a higher number of days with SPI above zero (Table 3), with exception of Serra Azul reservoir. In addition, Serra Azul and Barra Bonita reservoirs registered no days with extreme drought.

Table 3 – Percentage of days of Standardized Precipitation Index (SPI) results, according to drought category (McKee et al. 1993), for each reservoir.

Reservoir	Time period	n (months)	Normal or wet	Mild drought	Moderate drought	Severe drought	Extreme drought
			SPI≥ 0	−0.99 <SPI< 0	−1.49 <SPI< −1.00	−1.99 <SPI< −1.50	SPI≤ −2.00
Passaúna	1990-2020	360	51	35	6	3	5
Itupararanga	2008-2018	132	44	45	7	3	1
Barra Bonita	2010-2018	108	58	21	12	9	0
Promissão	2010-2020	132	64	26	0	1	9
Três Irmãos	2006-2020	168	53	38	2	1	6
Serra Azul	2010-2020	132	40	49	10	1	0
Paranoá	1990-2020	360	52	34	6	5	3

The existence of cascade reservoirs and the reservoirs operation should be considered in the analyzes of drought indices results. The reservoirs Barra Bonita, Promissão, and Três Irmãos are placed in Tietê river, and in spite of the drought indices pointing to extreme drought to Promissão and Três Irmãos reservoirs, due to their operation, also considering its use as a waterway, their volume variations (as discussed below) were not as affected as expected by the drought indices.

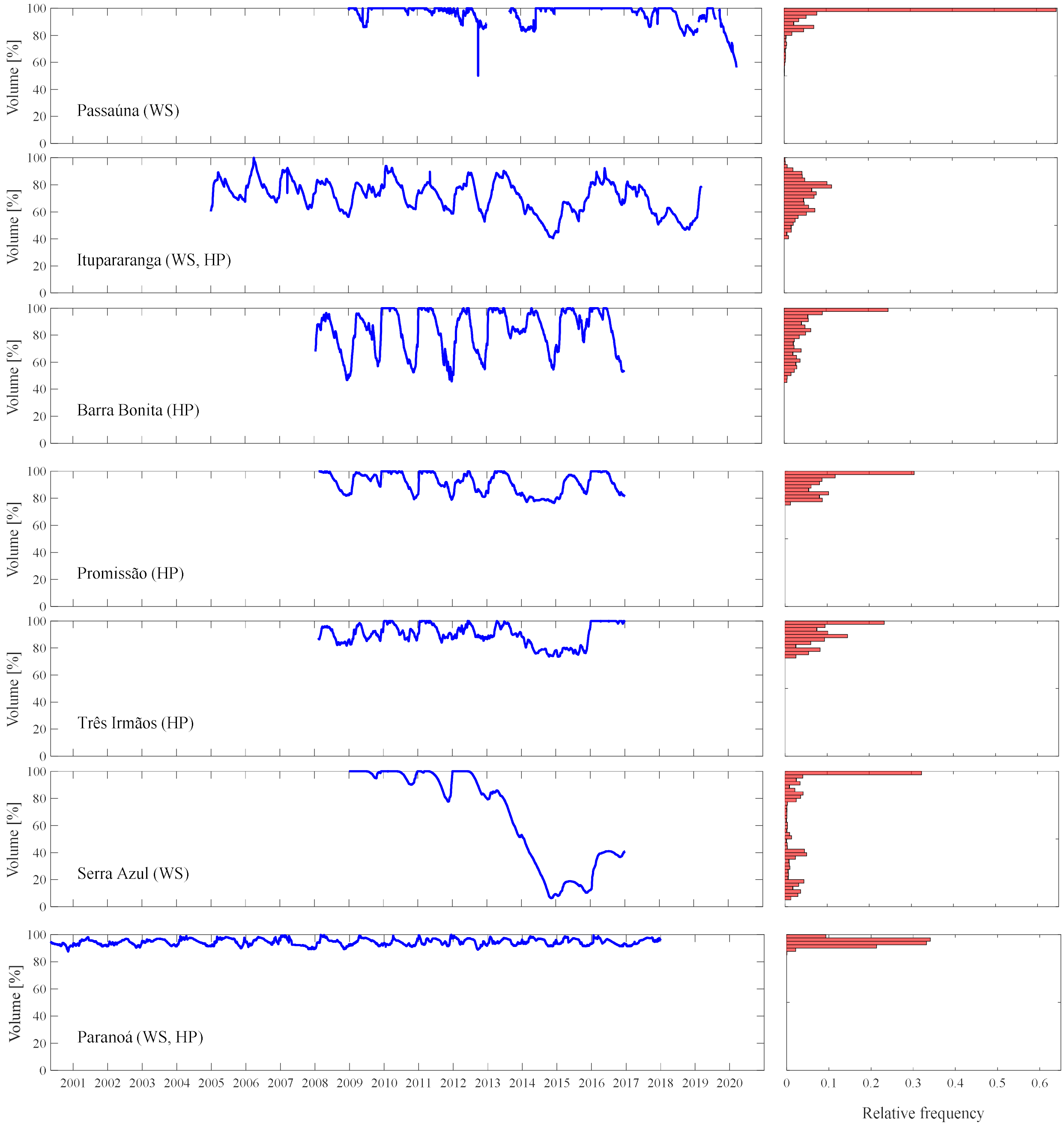
In this regard, drought indices are very useful for management purposes and drought monitoring, however, both indices did not include all reservoir parameters. Thus, the drought indices results should be interpreted together with information of hydrological reservoir monitoring, such as data of storage volume and water level.

Effects of drought on reservoirs volume

Reservoirs react differently to drought situations, as reservoir operations are differing considerably. Reservoir operation may include reduced intake flows for water rationing, maintenance of water levels for means of navigation, or may be influenced by reduced hydropower generation. This influences especially reservoir volumes and water levels, which are important parameters for the assessment of thermal dynamics and water quality. Figure 3 shows the variation of reservoir volumes and their occurrence frequency.

The reservoirs used for hydropower generation showed a higher oscillation of volume than the ones used for water supply purposes. This operational characteristic can hamper the identification of drought periods, especially if the drought assessment is based only on water level monitoring.

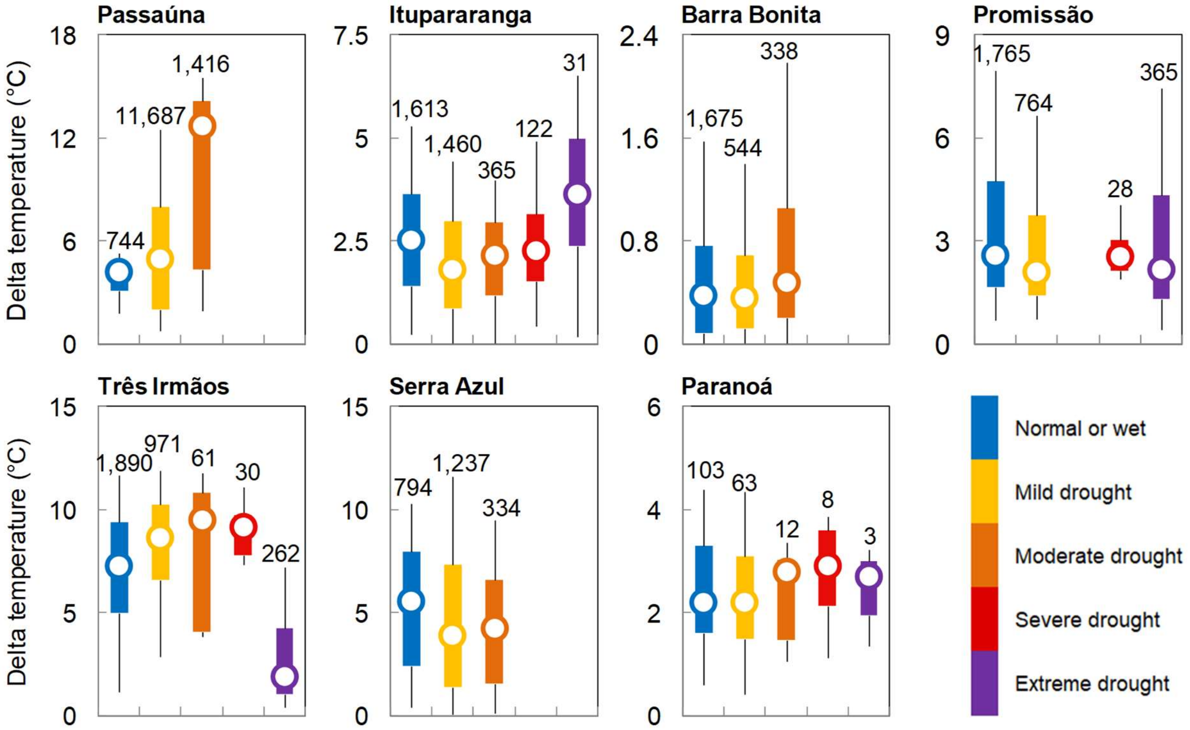
Figure 3 - Temporal variation of storage volume of reservoirs (%) and relative frequency of volume (%). Reservoir main use: WS is drinking water supply and HP is hydropower generation.



Effects of drought on reservoirs thermal dynamic

Water temperature responses may have different performances during drought periods (Mosley, 2015). The comparison of reservoir bottom surface temperature difference according to SPI category is presented in Figure 4.

Figure 4 – Temperature differences between surface and bottom for different meteorological periods in each reservoir.



Note: The numbers plotted inside of box plots indicate the n (number of observations) for each drought category. The data were presented with hourly time resolution for Passaúna, once a month for Paranoá and daily data for the others. The boundaries of the box plot indicate the 25th and 75th percentiles. Whiskers indicate the 5th and 95th percentiles. The white circle represents the median.

The reservoirs of Passaúna, Itupararanga, Barra Bonita, and Paranoá showed a similar tendency to increase the difference between surface and bottom water temperature when the drought became more severe. This result was counterintuitive, as water levels usually decrease during droughts, resulting in smaller depths, thus facilitate vertical heat transfer. It is assumed here that the reduced inflows resulted in less inflow-induced mixing and related density currents, thus resulting in more stable water columns. Três Irmãos showed an interesting result when extreme drought events were registered. In this extreme situation, the temperature difference was considerably reduced. This might be associated to other parameters, such as wind-induced mixing being more intense in drought periods in that region. However, such correlations were not made yet. Promissão reservoir did not present expressive differences. Serra Azul, in turn, showed a pattern of slight reduction of temperature differences during the moderate drought. A possible explanation for this might be that this reservoir presented a larger reduction of volume (less than 20%).

FINAL REMARKS

This study integrates unique features of Brazilian reservoirs, lessons learned, and opportunities for research as highlighted by Paiva et al. (2020). The occurrence of drought periods in different Brazilian regions in recent years draws the attention of water security issues since the drought periods have impacted water supply systems and also hydropower generation.

The effects of drought on reservoirs' thermal dynamics were presented here as an initial approach, that will be detailed and improved in future research. The additional assessment of physical reservoir indices, which combine dominant forcing parameters will be carried out as well as the integrative analyses among them. Future studies can also investigate other reservoir hydrodynamic indices as SDI (Standard Discharge Index) and apply other time scales for SPI (not only 12 months). In addition, the preliminary simulation period of the Passaúna reservoir, from August 2017 to February 2019, will be extended to capture the extreme drought event that occurred from 2019 until today (2021).

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REFERENCES

AGÊNCIA NACIONAL DE ÁGUAS - ANA (2017). Crise da água. Conjuntura dos Recursos Hídricos. Cap. 5, 39 p. Available at http://conjuntura.ana.gov.br/

BARBOSA, C. C.; CALIJURI, M. C.; DOS SANTOS, A.C.A.; LADWIG, R.; OLIVEIRA, L.F.A.; BUARQUE, A.C.S. (2021). "*Future projections of water level and thermal regime changes of a multipurpose subtropical reservoir (São Paulo, Brazil)*". Science of the Total Environment 770, https://doi.org/10.1016/j.scitotenv.2020.144741

BEGUERÍA, S.; VICENTE-SERRANO, S. M. (2017). SPEI: Calculation of the Standardised Precipitation-Evapotranspiration Index. R package version 1.7. Available at https://CRAN.R-project.org/package=SPEI

CUNHA, A. P. M. A.; ZERI, M.; LEAL, K. D.; COSTA, L.; CUARTAS, L. A.; MARENGO, J. A.; TOMASELLA, J.; VIEIRA, R. M.; BARBOSA, A. A.; CUNNINGHAM, C.; GARCIA, J. V. C.; BROEDEL, E.; ALVALÁ, R.; RIBEIRO-NETO, G. (2019). "*Extreme Drought Events over Brazil from 2011 to 2019*". Atmosphere 10, 642.

DAI, A. (2013). "*Increasing drought under global warming observations and models*". Nature Clim Change 3, pp. 52-58. https://doi.org/10.1038/nclimate1633

GELDA, R. K.; MUKUNDAN, R.; OWENS, E. M.; ABATZOGLOU, J. T. (2019). "*A Practical Approach to Developing Climate Change Scenarios for Water Quality Models*". Journal of Hydrometeorology 20, pp. 1197-1211.

HIPSEY, M. R.; BRUCE, L. C.; BOON, C.; BUSCH, B.; CAREY, C. C.; HAMILTON, D. P.; HANSON, P. C.; READ, J. S.; SOUSA, E. D.; WEBER, M.; WINSLOW, L. A. (2019). "*A General Lake Model (GLM 3.0) for linking with high-frequency sensor data from the Global Lake Ecological Observatory Network (GLEON)*". Geosci. Model Dev 12, pp. 473–523.

INMET, 2021. Automatic and Conventional Monitoring Stations (Estações automáticas e convencionais). Available at http://www.inmet.gov.br.

KUNDZEWICZ, Z. W.; MATA, L. J.; ARNELL, N. W.; DÖLL, P.; KABAT, P.; JIMÉNEZ, B.; MILLER, K. A.; OKI, T.; SEN, Z; SHIKLOMANOV, I. A. (2007). "*Freshwater resources and their management*", *in Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 173-210.
LIMA, J. E. F. W.; FREITAS, G. K. de; PINTO, M. A. T.; SALLES, P. S. B. de A. (Eds.). (2018). Gestão da crise hídrica 2016-2018: Experiências do Distrito Federal. Brasília, DF. ADASA, CAESB, SEAGRI, EMATER, DF. 328p. Available at http://www.adasa.df.gov.br/.
MCKEE, T.B.; DOESKEN, N.J.; KLEIST, J. (1993). "*The Relationship of Drought Frequency and Duration to Time Scales*". Proceedings of the 8th Conference on Applied Climatology, 17–23 January 1993, Anaheim, CA. Boston, MA, American Meteorological Society.
MOSLEY, L. M. (2015). "*Drought impacts on the water quality of freshwater systems; review and integration*". Earth-Science Reviews 140, pp. 203–214.
PAIVA, Rodrigo Cauduro Dias de et al. (2020). "*Advances and challenges in the water sciences in Brazil: a community synthesis of the XXIII Brazilian Water Resources Symposium*". RBRH 25, e50, 2020. http://dx.doi.org/10.1590/2318-0331.252020200136.
PARANÁ (2020). Decreto Estadual nº 4.626, de 07 de maio de 2020. Decreta situação de emergência hídrica no Estado do Paraná pelo período de 180 dias. Available at https://www.legisweb.com.br/legislacao/?id=395051.
PARANÁ (2021). Decreto Estadual nº 7.554, de 04 de maio de 2021. Decreta situação de emergência hídrica no Estado do Paraná pelo período de 90 dias. Available at http://www.aen.pr.gov.br/arquivos/0405crisehidrica.pdf.
READ, J. S.; WINSLOW, L. A.; HANSEN, G. J. A.; HOEK, J. VAN DEN; HANSON, P. C.; BRUCE, L. C.; MARKFORTF, C. D. (2014). "*Simulating 2368 temperate lakes reveals weak coherence in stratification phenology*". Ecological Modelling 291, pp. 142–150.
SALES, G. G. N. (2020). "*Water quality modeling in a subtropical water supply reservoir*". Dissertação - Universidade Federal do Paraná, Setor de Tecnologia, Programa de Pós-Graduação em Engenharia Ambiental. Curitiba, 2020.
SOARES, L.M.V.; SILVA, T.F.G.; VINÇON-LEITE, B.; ELEUTÉRIO, J.C.; DE LIMA, L.C.; NASCIMENTO, N.O. (2019). "*Modelling drought impacts on the hydrodynamics of a tropical water supply reservoir*". Inl. Waters https://doi.org/10.1080/20442041.2019.1596015.
TRENBERTH, K.; DAI, A.; VAN DER SCHRIER, G.; JONES, P. D.; BARICHIVICH, J.; BRIFFA, K. R.; SHEFFIELD, J. (2014). "*Global warming and changes in drought*". Nature Clim Change 4, pp. 17–22. https://doi.org/10.1038/nclimate2067
WINSLOW, L.; READ, J.; WOOLWAY, R.; BRENTRUP, J.; LEACH, T.; ZWART, J.; ALBERS, S.; COLLINGE, D. (2018). rLakeAnalyzer: Lake Physics Tools. R package version 1.11.4. Available at https://cran.r-project.org/package=rLakeAnalyzer.
World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016: Handbook of Drought Indicators and Indices (M. Svoboda and B.A. Fuchs). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.