Drought assessment in the São Francisco River Basin using satellite-based and ground-based indices

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LAPIS CAPES UNELLEZ

Outline

- **Introduction.**
- **Study Area.**
- **Materials and Methods.**
- **Results.**
- **Conclusions.**

Acronyms

- GRACE: Gravity Recovery and Climate Experiment .
- SMOS: Soil Moisture and Ocean Salinity.
- SPEI: Standardized Precipitation Evapotranspiration Index.
- scPDSI: self-calibrating Palmer Drought Severity Index.
- WSDI: Water Storage Deficit Index.
- GGDI: Groundwater Drought Index.
- SSI: Standardized Streamflow Index.
- SWDIa: Soil Water Deficit Index Anomalies.

Introduction

- With the advent of climate change, the severity, duration and spatial extent of **droughts are projected to increase in the São Francisco River Basin (SFRB)**.

- This situation carries serious implications for the **agriculture and hydroelectric sectors**, as those observed between **2012 and 2015**.

- **There is a need for a comprehensive exploration of this natural hazard**.

- **Drought is classified into four major types**: meteorological, hydrological, agricultural and socioeconomic drought.

- This work aims to analyze the concomitant impacts between the different types of droughts in order to understand their short-term and long-term characteristics in the entire SFRB. The major novelty is the use of the latest version of the **GRACE**, **SMOS-based soil moisture**, and **satellite-based scPDSI** datasets together with high-quality ground-based data to **delineate those areas of the SFRB where drought events are becoming more frequent and persistent**.

Study Area

- **Area**: ~ 621,812 km^2.
- **Federal states**: Bahia, Minas Gerais, Pernambuco, Alagoas, Sergipe, Goiás, and part of the Federal District.
- **Population**: ~ 14 million (~71.74 people per km^{-2})
- **Climate**: roughly 68% of the SFRB climate is Aw (tropical with wet summers and dry winters).
- **Annual mean precipitation**: 910 mm, ranging from around 400 to >1500 mm.
- **Rainy season:** the middle SFRB, from Nov to Jan, whereas from Jan to Mar in the northern basin.
- **Drivers of the weather system**: the temporal variability of precipitation is largely modulated by SST anomalies over the tropical Atlantic region and the ENSO phenomenon.

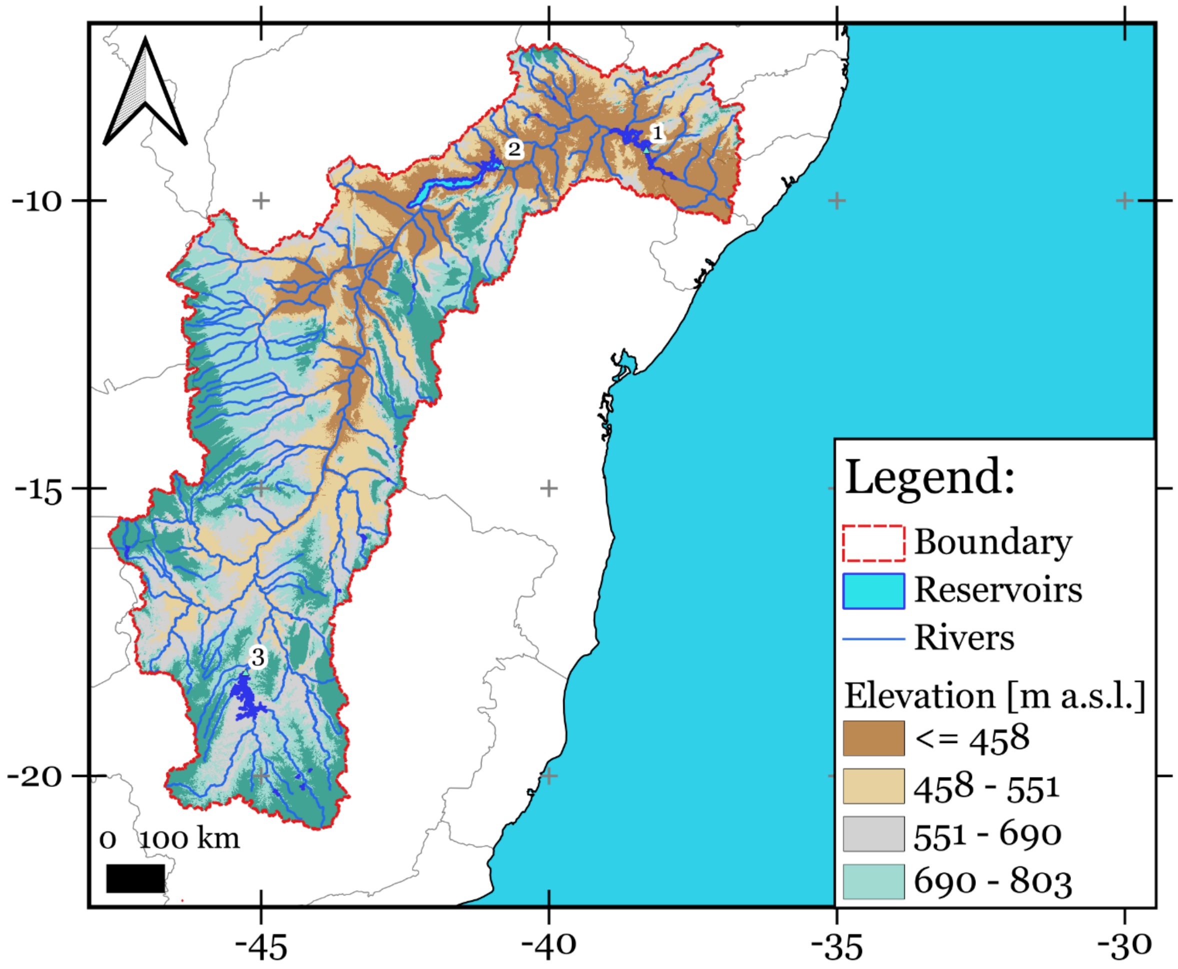

Fig. 1.- The study area showing the hydrographic network together with terrain elevation based on 90-m Digital Elevation Model—Shuttle Radar Topographic Mission (DEM-SRTM) images. The spatial distribution of reservoirs Itaparica (1), Sobradinho (2), and Três Marias (3) is shown.

Materials and Methods

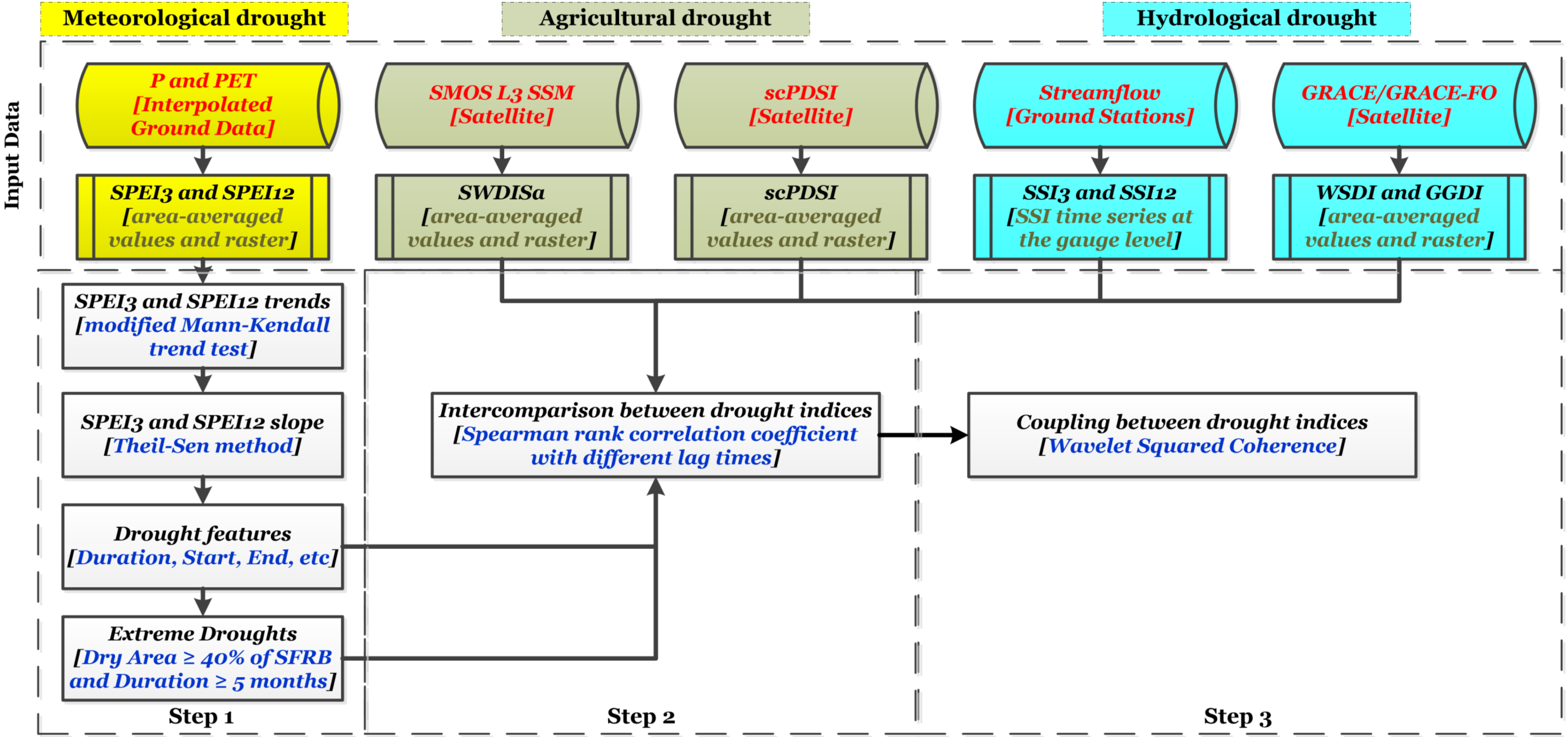

Fig. 2.- Flowchart of the methodological stages for the study.

Results: spatial–temporal trends of SPEI3 and SPEI12

- In terms of trends of SPEI3-DJF, -MAM, -JJA, and –SON for each year and during 1980-2015, a strong drought exacerbation in the middle and southern sub-basins during the JJA and DJF seasons was observed.

- Overall, 59% of the SFRB showed a significant drying trend (p ≤ 0.05) during the JJA season, while for the DJF, SON, and MAM seasons it was 16%, 14%, and 1%.

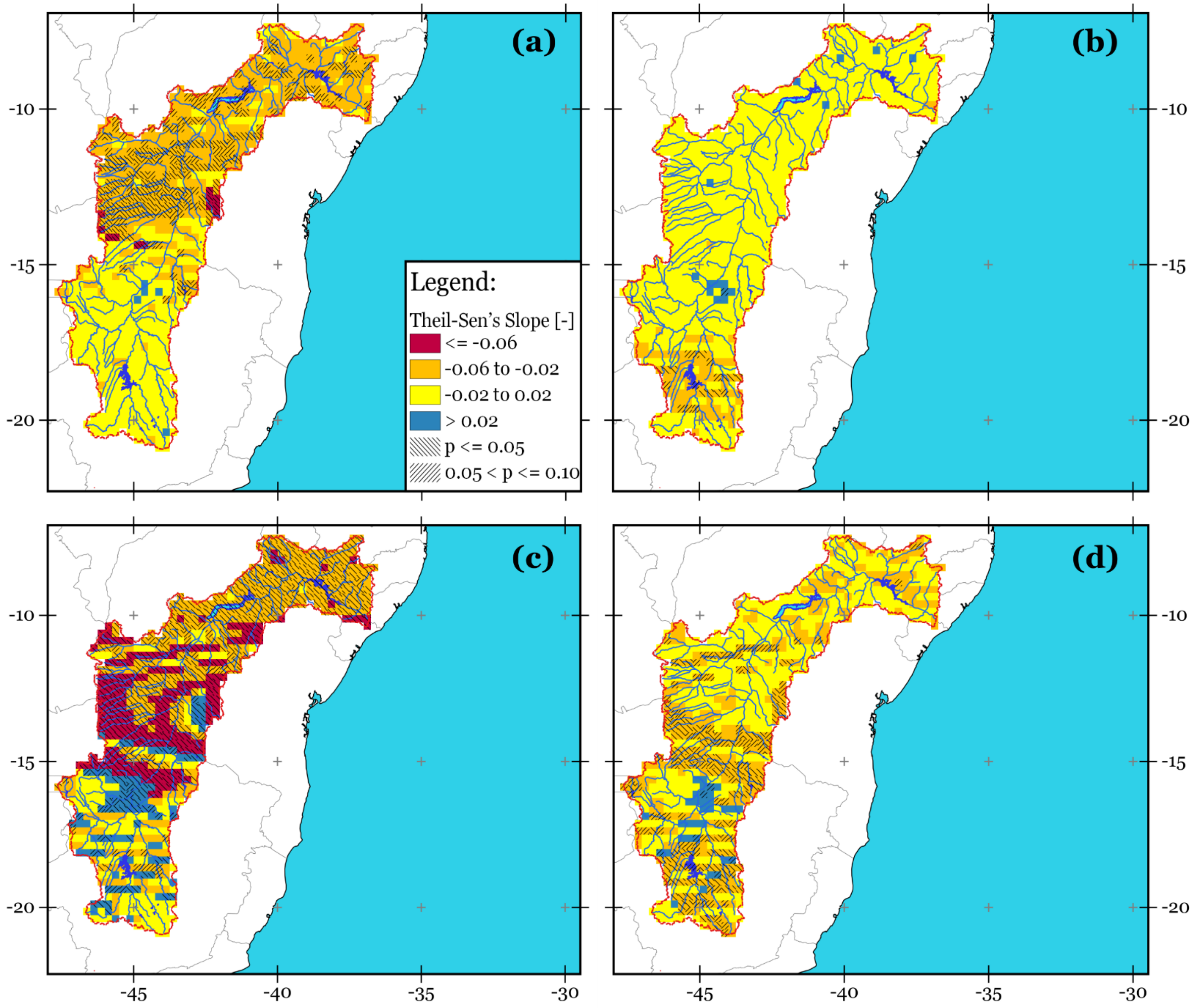

Fig. 3.- Spatial–temporal trend of SPEI3 at: (a) February (DJF); (b) May (MAM); (c) August (JJA), and (d) November (SON). The blue and orange-red tones represent areas with wetting and drying trends, respectively. The black hatched lines show those regions with statistical significant Theil-Sen's slope. The reference period of 1980-2015 was chosen for the calculation of the SPEI.

Results: spatial–temporal trends of SPEI3 and SPEI12 [1]

- All SPEI12-December drought categories had different magnitudes of trend in terms of Theil-Sen's slope. Those categorized as moderate drought showed the greatest magnitude of slope. However, neither of them was found to be significant (α = 0.05).

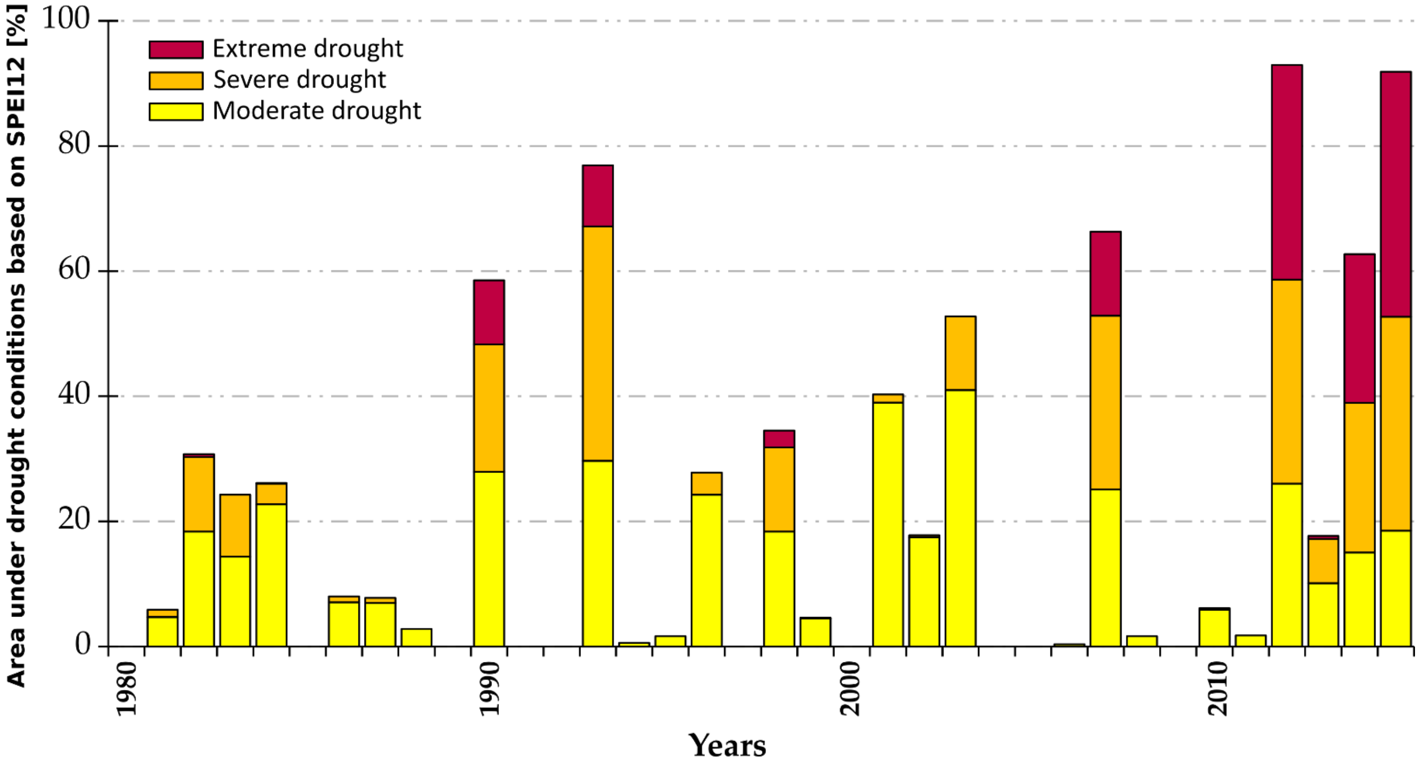

Fig. 4.- Percentage of area under drought conditions according to the values of SPEI12 at December in the SFRB during 1980-2015. The calculation of the area under drought conditions is based on the number of pixels within the SPEI drought categories: moderate dry, severe dry and extreme dry. The reference period of 1980–2015 was chosen for the calculation of the SPEI.

Results: spatial–temporal trends of SPEI3 and SPEI12 [2]

- All SPEI3 drought categories showed a positive Theil-Sen's slope, which indicates the increasing of the area under drought conditions. However, only those classified as moderate drought or extreme drought exhibited a significant monotonic trend into the winter season (i.e. JJA) since the 1980s.

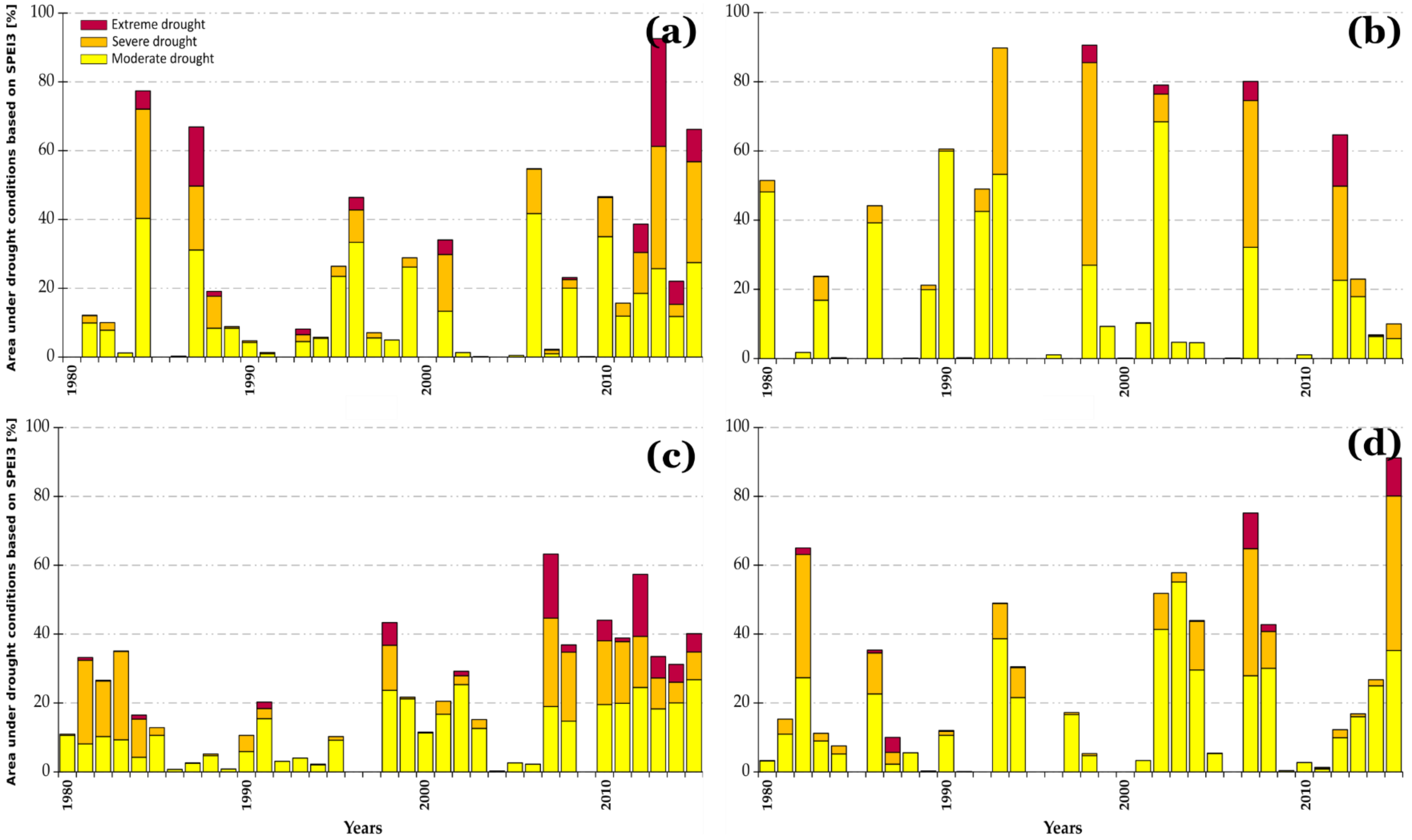

Fig. 5.- Same as Figure 4, but for the values of SPEI3 at: (a) February (DJF); (b) May (MAM); (c) August (JJA), and (d) November (SON). .

Results: extreme drought events for the period 1980-2015

Table 1.- Main features of the extreme drought events identified over the SFRB during 1980–2015.

Time Scale [Months]	Event	Start [Date]	End [Date]	Duration [Months]	Average SPEI [-] [1]	Dry Area Peak [%] [2]	Severity [-]
SPEI3	E1	April-98	October-98	7	-1.69	90.58	11.82
	E2	May-07	January-08	**9**	-1.73	80.09	**15.61**
	E3	March-12	October-12	8	**-1.78**	94.67	14.27
	E4	August-15	December-15	5	-1.75	**95.99**	8.76
SPEI12	E1	April-98	November-98	8	-1.76	90.69	14.06
	E2	October-07	August-08	11	-1.73	87.16	19.00
	E3	April-12	November-13	20	-1.83	**92.93**	36.55
	E4	January-14	December-15	**21**	**-1.86**	91.86	**44.63**

Note: For the extreme drought event shown: [1] it was calculated considering only values of SPEI ≤ −1.00; [2] it is the maximum value of the percentage of pixels with values of SPEI ≤ −1.00. The values in **bold** correspond to the extreme value for each time scale and feature.

- The most severe event for each time scale occurred from May 2007 to January 2008 (SPEI3) and from January 2014 to December 2015 (SPEI12). This last event was the worst extreme drought event in terms of severity (44.63), duration (21 months) and spatial coverage (91.86%).

Results: paired intercomparison between the drought indices

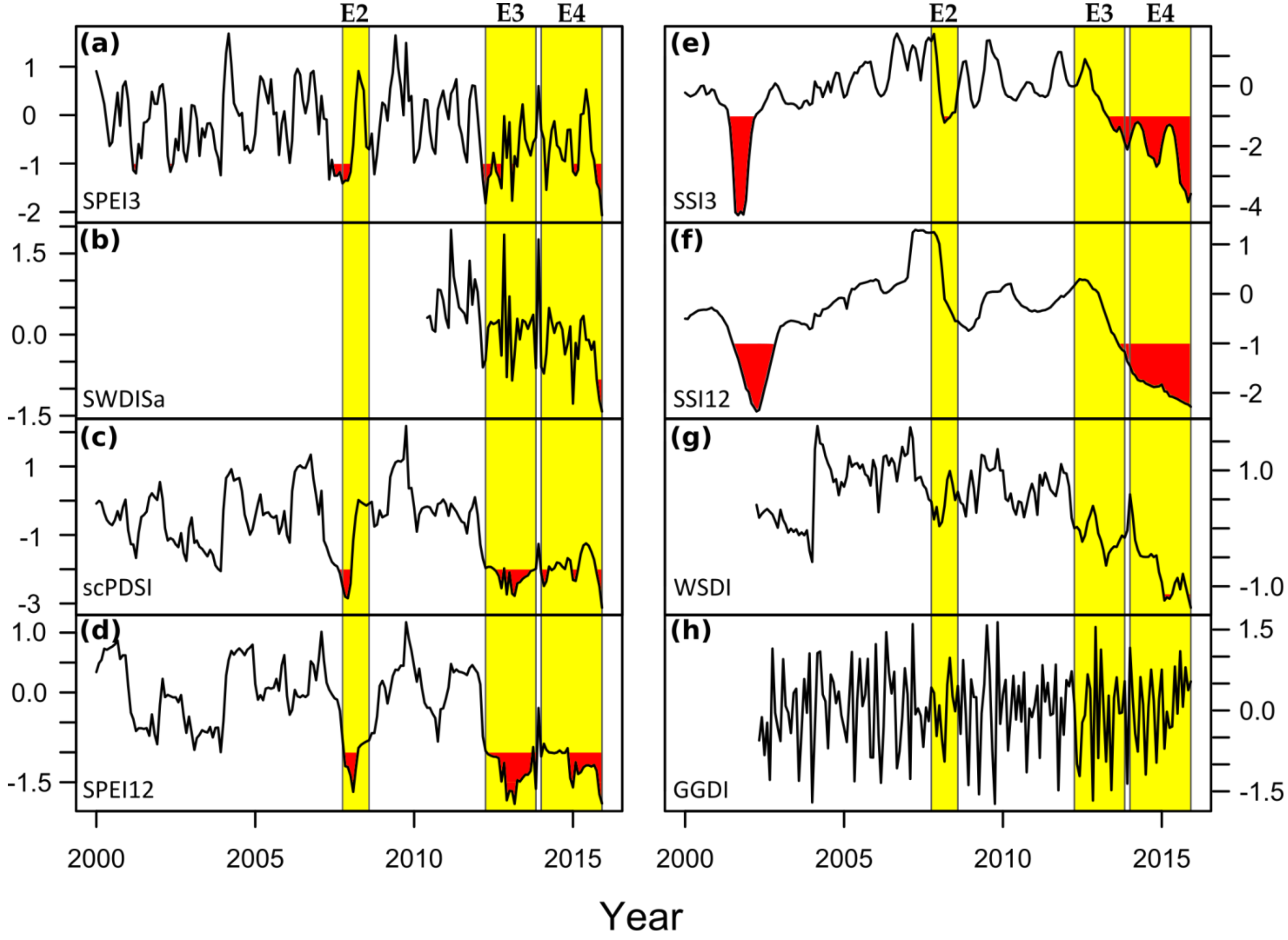

Fig. 6.- Temporal variation of the area-averaged values over the entire SFRB of the: (a) SPEI3 during 2000–2015; (b) SWDISa during 2010–2015; (c, d) scPDSI and SPEI12 during 2000–2015; (e, f) SSI3 and SSI12 at the streamflow gauge Propriá during 2000–2015; (g, h) WSDI and GGDI during 2002–2015. The yellow shaded periods on the panels (a) to (h) indicate the occurrence of the SPEI12-based extreme drought events E2, E3, and E4 shown in Table 1. Red shaded area corresponds to drought conditions for each drought index.

- SWDISa and scPDSI are more sensitive than other drought indices to short-term changes in precipitation.

Results: recent variations in agriculture and hydrological droughts based on scPDSI and WSDI

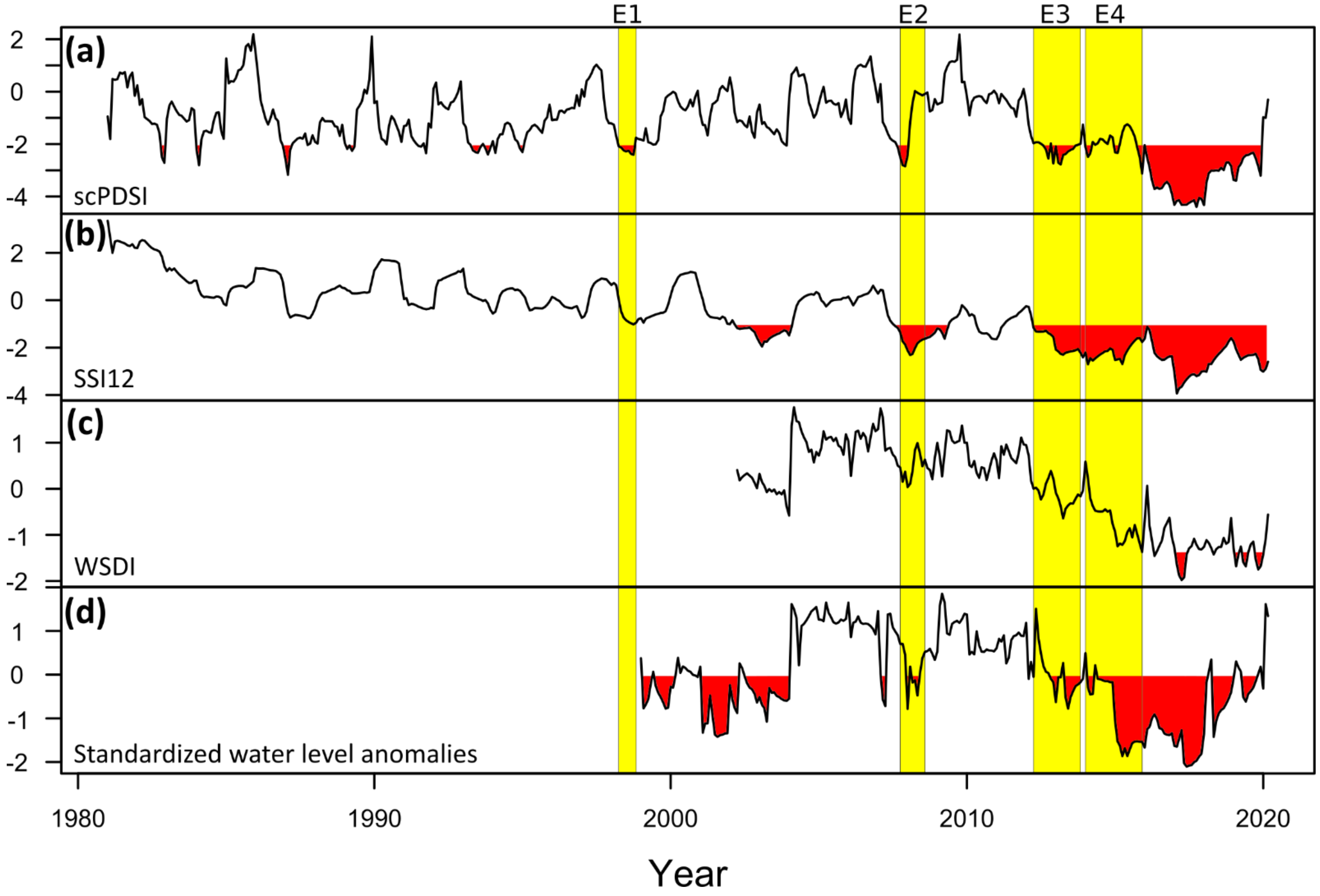

Fig. 7.- Temporal variation of the area-averaged values over the entire SFRB of the (a) scPDSI during 1981–2020 and (c) WSDI during 2002–2020. Temporal variation of values of (b) SSI12 at the Boqueirão streamflow gauge during 1981–2020 and (d) standardized anomalies for the water level at the Sobradinho reservoir during 1999–2020 (reference period: 1999–2020). The yellow shaded periods on the panels (a) to (d) indicate the occurrence of the SPEI12-based extreme drought events E1, E2, E3, and E4 shown in Table 1. Red shaded area corresponds to drought conditions for each drought index, while this correspond to negatives anomalies for the water level at the Sobradinho reservoir. The water level at the Sobradinho reservoir provided by the National Electric System Operator (https://bit.ly/3hhz3p3) .

Conclusions

- A moderate basin-wide drying trend at annual time scale affected the middle and south regions of the SFRB from 1980 to 2015, coinciding with the ENSO phenomenon and SST anomalies in the tropical Atlantic.

- An expansion of the area under drought conditions was observed during the winter months (i.e. JJA), but there was no evidence of a significant positive trend in the remaining seasons in terms of spatial coverage between 1980 and 2015.

- The long-term extreme drought events showed increasing trends in terms of severity and duration, but this characteristic was not observed on a seasonal time scale during 1980-2015.

- The SWDISa and WSDI showed a good performance in assessing agricultural and hydrological droughts across the whole SFRB.

- A marked depletion of groundwater levels concurrent with increase in soil moisture content was observed during the most severe drought conditions, which means an intensification of the groundwater abstraction for irrigation.

Thanks for your attention

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