Timing of Drought Onset Controls Hydrological Drought Responses in Tropical Catchments

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January 20, 2023

Abstract

Understanding onset of droughts and its potential linkage to resulting responses like severity (deficit volume) is crucial for providing timely information related to drought sectors including the cultivation planning and monitoring crop productivity. Using high-quality daily observed streamflow records from 82 medium-to-large sized catchments over (tropical) peninsular India, we show that the variability in onset timing drives the severity of hydrological droughts. The strength of onset timing-severity relationships using observed records indicate seasonality of rainfall and catchment characteristics mainly modulate hydrological drought responses in peninsular India, which is not readily apparent from land-surface model simulations. The observed trend for mean onset of drought depicts delayed occurrence for more than half of the catchments. Around one-third of the catchments shows a stronger non-linear significant dependency (>0.7) between severity and onset of drought. The findings of the study highlight the need for accounting feedback between drought onset and severity and their concurrent changes for seasonal-to-sub-seasonal predictability of droughts; and contributes to discussions on building resilience to extreme droughts in a changing climate.

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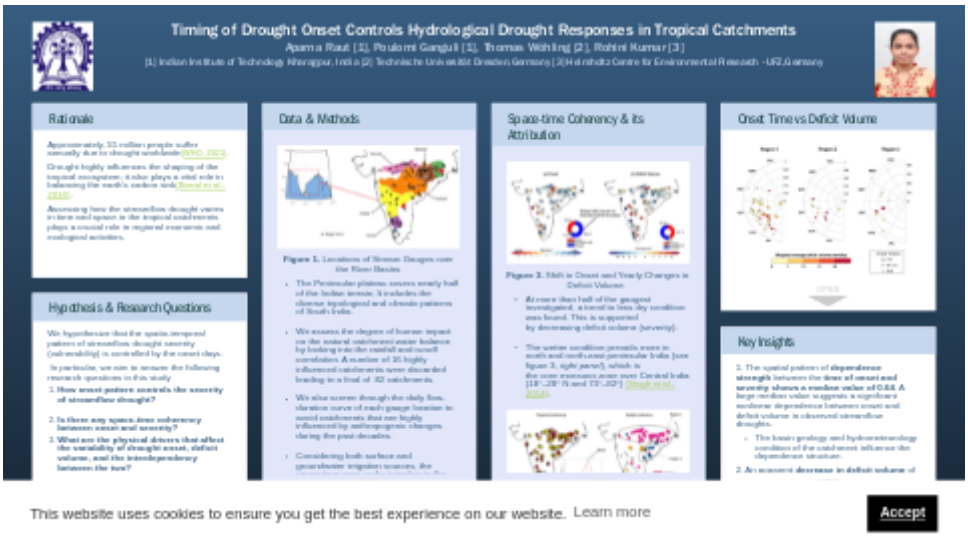

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PRESENTED AT:

RATIONALE

Approximately, 55 million people suffer annually due to drought worldwide(WHO, 2021) (https://www.who.int/health-topics/drought#tab=tab_1).

Drought highly influences the shaping of the tropical ecosystem; it also plays a vital role in balancing the earth's carbon sink(Bonal et al., 2016) (https://doi.org/10.1007/s13595-015-0522-5).

Assessing how the streamflow drought varies in time and space in the tropical catchments plays a crucial role in regional economic and ecological activities.

HYPOTHESIS & RESEARCH QUESTIONS

We hypothesize that the spatio-temporal pattern of streamflow drought severity (vulnerability) is controlled by the onset days.

In particular, we aim to answer the following research questions in this study

1. **How onset pattern controls the severity of streamflow drought?**
2. **Is there any space-time coherency between onset and severity?**
3. **What are the physical drivers that affect the variability of drought onset, deficit volume, and the interdependency between the two?**

DATA & METHODS

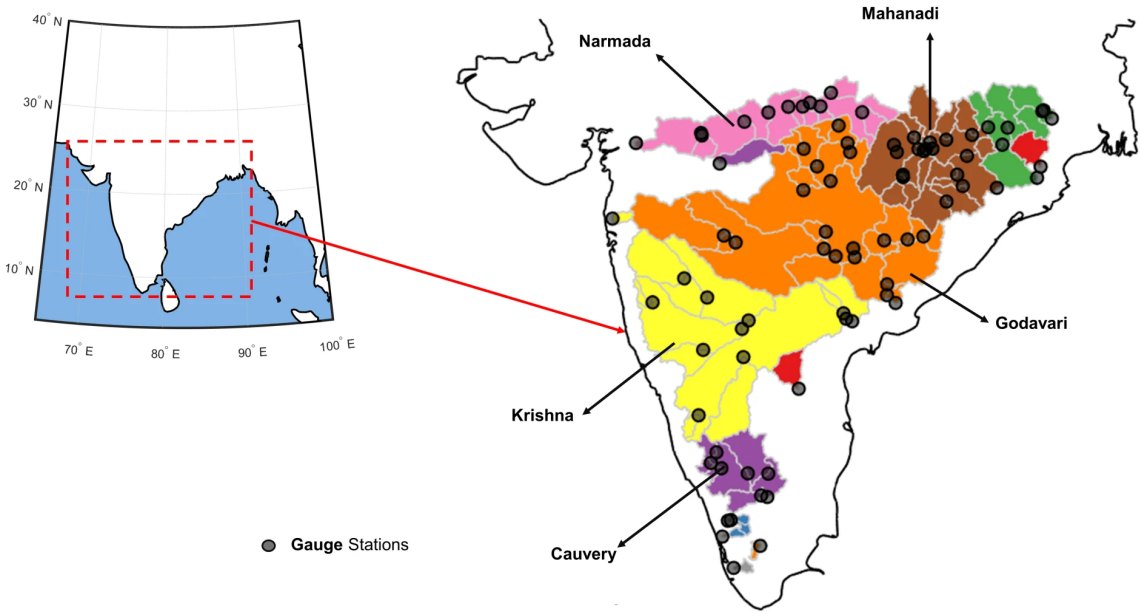

Figure 1. Locations of Stream Gauges over the River Basins

- The Peninsular plateau covers nearly half of the Indian terrain; It includes the diverse topological and climatic patterns of South India.
- We assess the degree of human impact on the natural catchment water balance by looking into the rainfall and runoff correlation. A number of 16 highly influenced catchments were discarded leading to a final of 82 catchments.
- We also screen through the daily flow-duration curve of each gauge location to avoid catchments that are highly influenced by anthropogenic changes during the past decades.

- Considering both surface and groundwater irrigation sources, the percentage area under irrigation in the individual catchments varies from 3-33%, with a median irrigated area of ~16%.

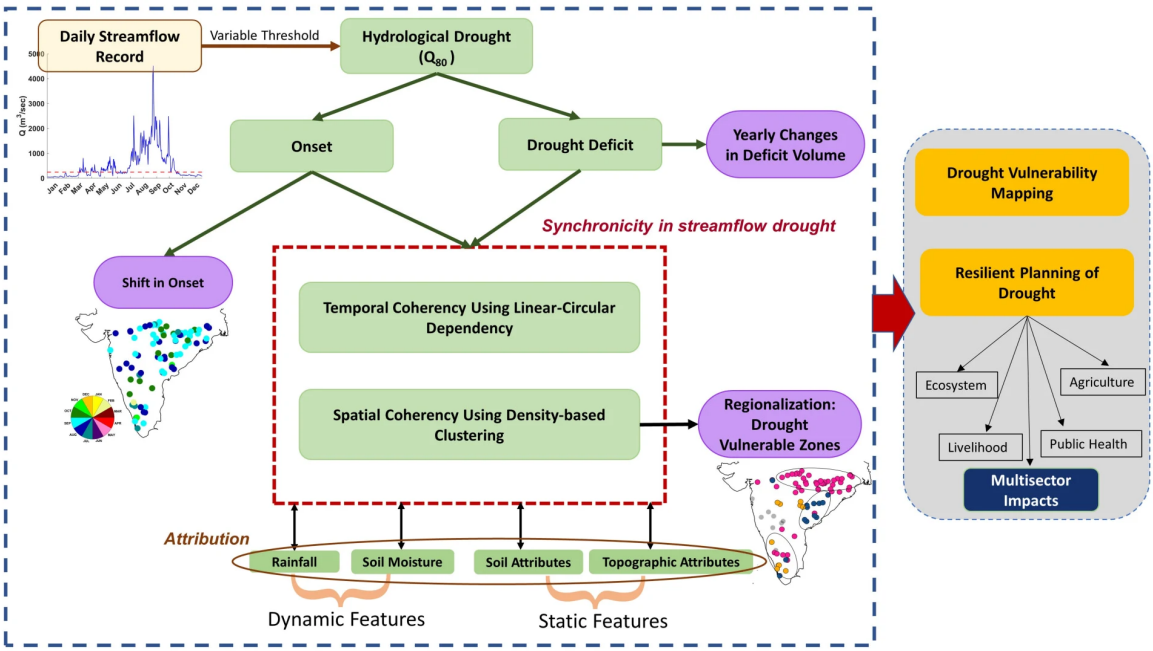

Figure 2. Detailed Workflow

SPACE-TIME COHERENCY & ITS ATTRIBUTION

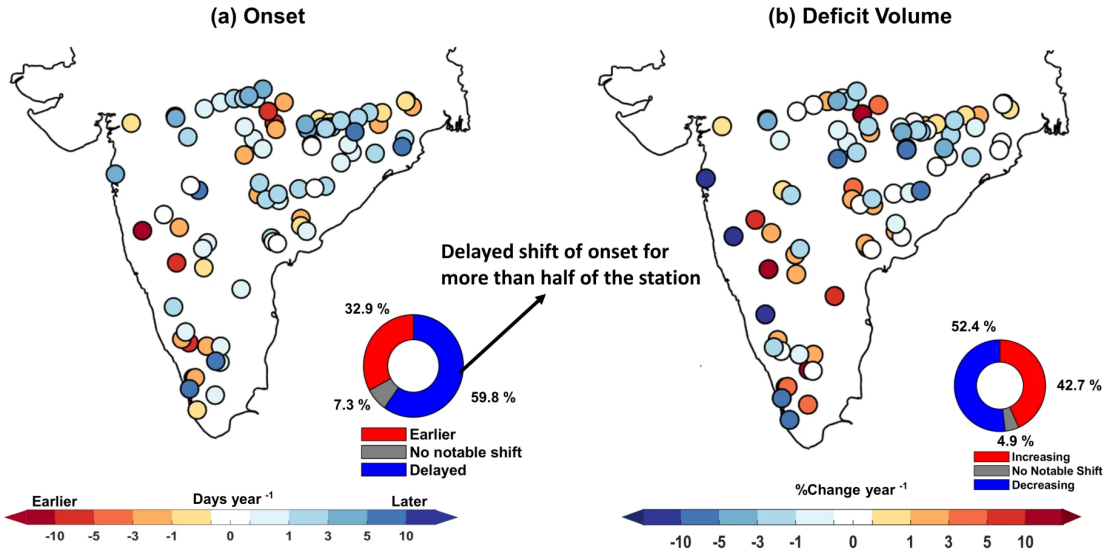

Figure 3. Shift in Onset and Yearly Changes in Deficit Volume

- At more than half of the gaugest investigated, a trend to less dry condition was found. This is supported by decreasing deficit volume (severity).
- The wetter condition prevails more in north and north-east peninsular India (see figure 3, *right panel*), which is the core monsoon zone over Central India (18°–28° N and 73°–82°) (Singh et al., 2014) (https://www.nature.com/articles/nclimate2208).

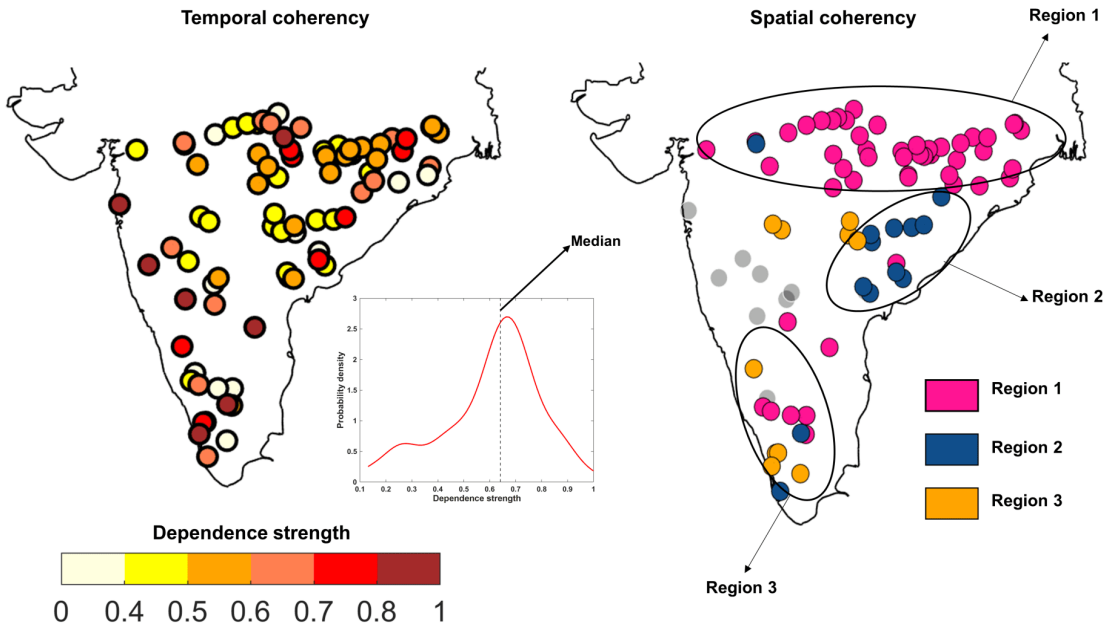

Figure 4. Spatio-temporal Coherency

- The linear-circular dependency between the mean onset and deficit volume represents the temporal coherency.
- Krishna river basin shows higher strength of dependency that varies between 0.6 to 0.92 (see figure 4, *left panel*).
- To assess inter-regional differences in cluster properties (dependence strength between the mean onset and deficit volume), we use the Wilcoxon-rank sum test.
- While localized assessment of Wilcoxon rank-sum test shows regions 2 and 3 are spatially different at 5% significance (p-value = 0.04), the Bonferroni corrected p-values for pair-wise

comparison indicate, the inter-regional differences are statistically indistinguishable (p-value>0.1).

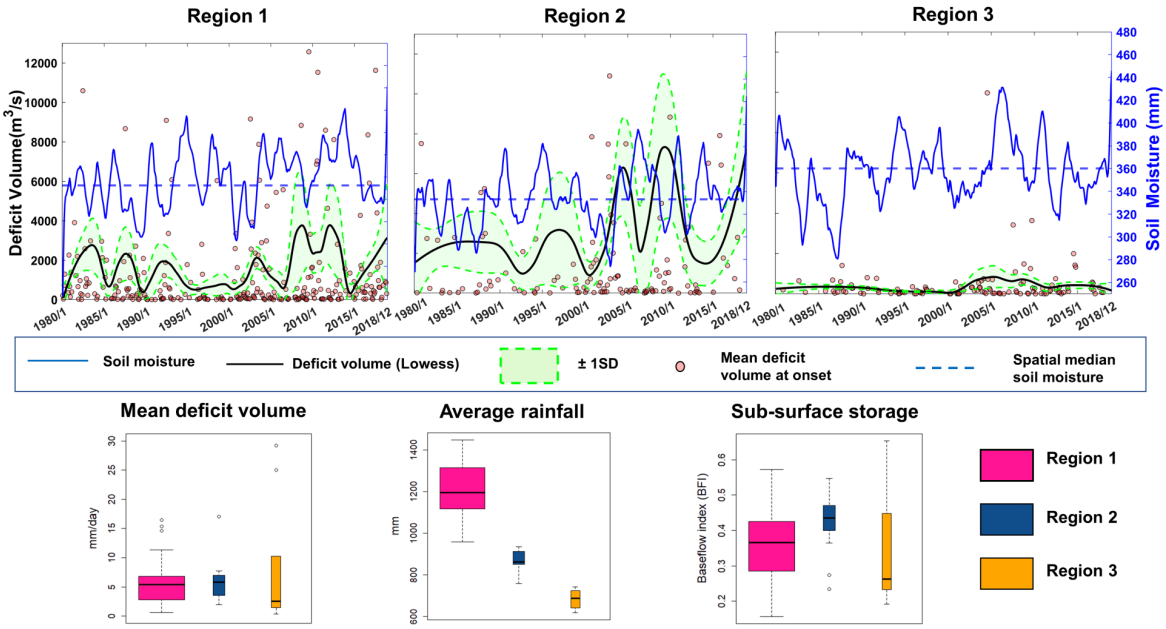

Figure 5. Attribution of Different Dynamic Property

- On average higher soil moisture (at depth 1.6m, Dool et al,2003 (http://doi.org/10.1029/2002JD003114)) in region 3 dampens the deficit volume of streamflow drought.
- The high baseflow index(BFI) indicates permeable geology of region 2.
- During a deadly hydrological drought of the year 2000-2003(Mishra.,2020) (https://doi.org/10.1016/j.jhydrol.2019.124228), region 2 with high BFI contributes towards groundwater sustenance(Kelly et al.,2020) (https://www.mdpi.com/2073-4441/11/5/901). leading to lower deficit volume.
- The least median baseflow at region 3 indicates rivers in this area are flashy in nature indicating higher sensitivity of seasonal rainfall to streamflow.

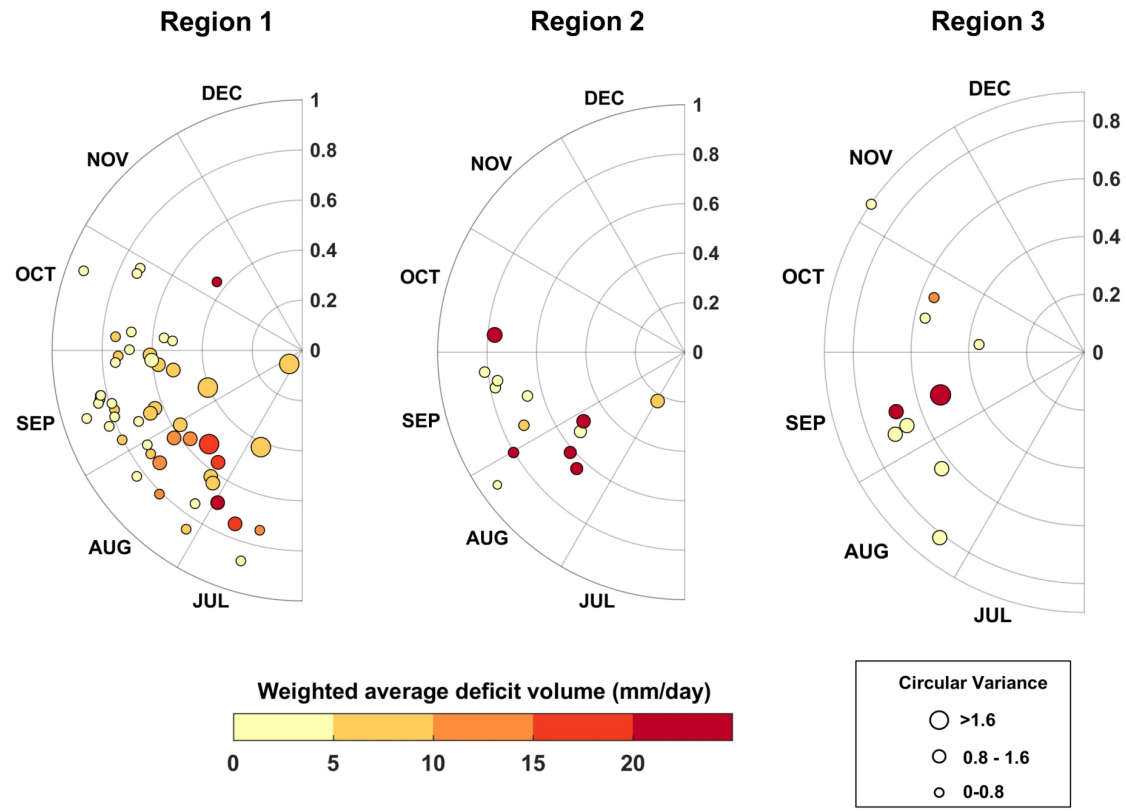

Figure 6. Region-wise Relation between Mean Onset and Weighted Average Deficit Volume

- Weighted average deficit volume also takes the duration of droughts into account while quantifying.
- Region 1 has modest deficit volume with high variance, in contrast to region 2 with, high deficit volume and less variability.
- Region 2 is more drought-prone due to low soil moisture (see figure 5) and has a high weighted average deficit volume.

KEY INSIGHTS

1. The spatial pattern of **dependence strength** between the **time of onset and severity shows a median value of 0.64**. A large median value suggests a significant nonlinear dependence between onset and deficit volume in observed streamflow droughts.

- The basin geology and hydrometeorology condition of the catchment influence the dependence structure.

2. An apparent **decrease in deficit volume** of observed streamflow drought is accompanied by a **delay in the time of onset** - this is pronounced over catchments located in the core monsoon region (Region 1: Figure 3)

- Delayed occurrence of drought could be related to shifting in monsoon dynamics over the Indian subcontinent((http://https//doi.org/10.1029/2019GL083875) Loo et al.,2015, (https://doi.org/10.1016/j.gsf.2014.02.009)Devanand et al.,2019) (http://doi.org/10.1029/2019GL083875).

3. Despite high BFI, relatively **low rainfall, results in a low soil moisture** build-up at region 2, which controls high drought deficit volume in this regime. This explains the large variability in onset.

4. The rainfall variability plays a crucial role in deciding the onset and severity of the streamflow drought event together with catchment characteristics and soil properties.

- A low BFI indicates rivers in this area are more flashy in nature indicating higher sensitivity of seasonal rainfall to streamflow (Region 3). This also indicates a short rainfall event during a prolonged dry period will result in a relatively slower rate of drought recovery owing to a smaller rise in streamflow as compared to a fast-responding catchment (Region 2: Figure 5; lower panel).
- Soil moisture controls drought resilience at Region 3. Despite a low BFI, a high value of soil moisture results in a low deficit volume

5. The space-time coherency between drought onset and severity helps to identify three distinct regimes.

- It aids in identifying drought vulnerable regions, forecast, and water resources planning.

DISCLOSURES

The work is supported by DST SERB (grant ID: SRG/2019/000044).

AR is also grateful to the German Academic Exchange Service(DAAD), for granting Combined Study and Practice Stays for Engineers from Developing Countries (KOSPIE) with Indian IITs, 2020 (57525292).

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