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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Drought monitoring and prediction in climate vulnerable Pakistan: Integrating hydrologic and meteorologic perspectives" *by* Taimoor Akhtar et al.

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General Comments

Th paper explores the relationship between meteorological and hydrological droughts in snow-dominated catchments of Pakistan in West Asia. The study aims to provide research findings that can be used in regional operational drought monitoring and early warning based on Standard Precipitation and Evaporation Index (SPEI) and Standard Streamflow Index (SSI). The two indices are calculated as meteorological and hydrological drought during identified drought events between 1961 and 2018. Seasonal and lagged cross-correlations between both indices is analyzed and drought characteristics

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Discussion paper

in terms of drought duration and severity are investigated. Five parametric distributions are fitted for calculating SSI.

I believe that the paper requires major revisions. Research assumptions and novel aspects of the study need to be added and highlighted. It is not surprising that a meteorological drought may develop and end rapidly, while the onset of hydrological/agricultural droughts responds to a meteorological drought with some time lag because of hydrological indicators such as soil moisture or reservoir effect. The paper has not addressed benefits/limitations of SPEI and SSI compared to other indices. Additional discussions are required for justifying selected drought indices among other meteorological, agriculture and hydrological drought indices which have not been mentioned in the manuscript but have been investigated in similar research studies in West Asia. Additional analysis and discussions should be addressed with respect to selection of an appropriate probability distribution function for SSI. It is suggested that authors indicate how different aspects of drought characteristics differs in one particular/selected extreme drought event(s) which have had different dynamics. Suggestions for future studies should be addressed based on aspects which have not been taken into consideration in the scope of current study (e.g. comprehensive drought analysis based on inter-comparison of more indices, aspects relevant to agricultural drought).

Specific Comments

- I was not able to find any methodology or findings with regard to drought prediction in the paper. Therefore, I suggest omitting the world “prediction” from the title.

- Line 4: It is suggested to use both terms of “indicator” and “index” based on established definitions in the entire manuscript. For example, you might refer to definitions provided in:

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.

- Lines 123-126: There are other observation-based gridded data available in the study region for precipitation, e.g. APHRODITE in Monsoon Asia domain (http://aphrodite.st.hirosaki-u.ac.jp/products.html). In addition, recent datasets have been developed based on several information and not solely based on reanalysis which their performance must be investigated compared to reanalysis or station-based dataset. For example:

Beck, H. E., Wood, E. F., Pan, M., Fisher, C. K., Miralles, D. M., van Dijk, A. I. J. M., McVicar, T. R., and Adler, R. F. 2019. MSWEP V2 global 3-hourly 0.1 precipitation: methodology and quantitative assessment, Bulletin of the American Meteorological Society 100(3), 473–500.

- Is there any particular reason why CRU TS4.03 is selected among other available dataset? Authors may provide additional arguments on this point.

- The time period of meteorological data used for SPEI calculation must be provided.

- Line 83: In order to claim and highlight that gridded climate datasets can be a reasonable alternative to station data for drought analysis in catchments under study, referring to other studies is not enough. At least, uncertainty of several grided data must be investigated and communicated and a comparison between existing station and gridded data be investigated based on existing literature.

- Line 96 – Figure 1: Please use the same map projection as figure 2. A map which shows the location of four western river catchments together with upper and lower Indus can be significantly informative.

- Line 96 – Figure 1: Why the period of 1901 to 2018 is considered for drawing the map? It is very likely that homogeneity of data in the early century is influenced by number of stations which has been used in CRU dataset.

- Please provide maps for the similar period used for the streamflow (1968-2018).

- Method which is used to calculate PET must be explained.

- Providing the extent of Indus Basin Irrigation System (IBIS) in either Figure 1 or 2, can significantly help to understand area under study and for mechanisms of drought management.

- Is there any significant agricultural activities upstream of selected streamflow gauge stations?

- The role of reservoirs in water resources and drought management needs to be highlighted.

- Line 130: Providing monthly time series of streamflow records of four selected gauges can help understanding hydrological regime in the region.

- Section 3.1. The performance evaluation and inter-comparison of different drought indices is necessary for identifying and selecting appropriate drought indices which has been addressed by authors. However, it is not conclusive why SPEI and SSI are selected specifically for representing meteorological and hydrological droughts in the study region? For example, several studies have shown the high performance of Effective Drought Index (EDI) which is also a standardized index. Discussions on criteria for selection of suitable drought indices in the research must be explained based on evaluation of several indices (more than two) and in the context of their performance in early warning of drought's onset, severity, persistence, and spatial extent within region under study. At minimum, the performance of other drought indices which was assessed for basins with similar climate in West Asia must be addressed. For example:

Wable, P.S., Jha, M.K. and Shekhar, A. 2019. Comparison of Drought Indices in a Semi-Arid River Basin of India. Water Resources Management, 33, 75–102. https://doi.org/10.1007/s11269-018-2089-z

- Section 3.1. With respect to general information provided in lines 49-56, why authors did not explore agricultural drought based on soil moisture which is relevant for Indus

Basin Irrigation System (IBIS) planning?

- Line 159: There are other meteorological indices which are based on both precipitation and potential evapotranspiration and do not have complexity of fitting probability distribution (e.g. Reconnaissance Drought Index (RDI)). Please provide argument on selection of SPEI over same indices.

- Line 166: It looks like that the basis of all analysis to evaluate the coherence between the two drought indices is SPEI calculated based on areal-average (at catchment level) and its comparison to the gauge point at the outlet of the corresponding catchments. However, Figure 11 suggests that spatial variability of SPEI can be high for a particular drought event at least for Indus sub-basin. Authors require to provide convincing arguments to support any assumptions made on the subject.

- Line 176: Standard Streamflow Index (SSI) should not be confused with the Standardized Runoff Index (SRI), see e.g. Shukla and Wood (2008).

- Averaging meteorological fields over a spatial domain can have a smoothing effect of extreme values especially in complex topographies. In addition, comparison of two indices which are calculated in the same spatial domain (grid to grid/ areal-average to areal-average/pointwise) is more reasonable than comparing an index which is calculated by areal-averaging (SPEI in this case) with another index which is calculated on its outlet (SSI in this case).

- Since SRI can be calculated and provided based on the same resolution as SPEI, authors are requested to argue why they SSI is selected over SRI.

- Section 3.1.2. To avoid the computational burden in fitting parametric distributions, it is a common practice to use an empirical cumulative probability distribution. Authors are suggested to provide additional discussion on comparison between parametric and nonparametric approaches for calculating SSI to fulfil the purpose mentioned in lines 358-359.

- Section 3.3 The title section might not well represent the contents of this section. Cross-correlations and lagged cross-correlations between meteorological and hydrological drought indices is introduced in this section as methods to investigate drought characterization and the use of term “integrating” for this case might be misleading.

- Figure 7: It is not clear if streamflow gauges record reservoir inflow or outflow? With regard to that point, please provide reasoning why Jhelum and Kabul have higher drought durations based on SSI? Authors might argue with respect to how hydrologic memory plays role in those sub-basins in terms of groundwater storage, reservoir, snowpack, and soil moisture.

- Figure 8: Please specify if the figure is based on areal-average of all four catchments and provide the same heat-map based on SSI-3 and SSI-6.

- Line 299: Readers might expect results based on statistical methodologies which are applied to identify possible trend components in any hydro-meteorological time series whereas monthly cross correlations are investigated in this section. It is recommended to modify title accordingly.

- Line 314-315: Attributing weak cross-correlations for summer and fall to CRU error needs to be verified with other datasets.

- Figure S3: Representing a flood event based on monthly evaluation of SPEI-12 needs to be reconsidered.

- Lines 375-380: The title suggests integrating hydrologic and meteorologic perspectives is the one aim of the study based on analysis of SPEI and SSI. Cross-correlation and lagged cross-correlations are calculated to evaluate the relation between two indices. Authors finally conclude that SPEI could be used in operational drought forecasting and warning system based on strong correlations. However, I believe that this conclusion is highly controversial as a drought index which is going to be used for operational regional drought monitoring and prediction system must be robust for

different hydroclimate conditions and in areas where spatiotemporal variability of hydroclimate variables is high, for all months. In addition, the uncertainty of gridded data has not been thoroughly investigated in this study and many of the findings reported in the manuscript are based on analysis of indices calculated in different spatial domains (areal-average against point measurements). Authors should provide strong arguments on the concerns mentioned above.

Technical Comments

- Please Check punctuations in entire manuscript for period and comma (e.g., in lines 28, 104, 296)

- Line 140: Use appropriate way for citations at the end of the sentence.

- Line 158: A paragraph contains more than one sentence.

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