

## ***Interactive comment on “Spatiotemporal Changes in Aridity of Pakistan during 1901–2016” by Kamal Ahmed et al.***

**Anonymous Referee #2**

Received and published: 13 March 2019

This paper analyzes spatial patterns of aridity across Pakistan and attempts to attribute spatial and temporal changes in these patterns to changes in precipitation and potential evapotranspiration (PET). The paper shows that Pakistan is becoming less arid over a large region (the Northeast), most likely due to increases in precipitation, which seems to contrast with the findings of previous studies.

Overall, I found the variety of statistical tests performed an interesting way to attribute the change in aridity to changes in precipitation with some degree of confidence. However, I was surprised that the paper failed to emphasize the clear geographic correspondence between changes in aridity and precipitation trends shown in Figures 4-5.

My biggest criticism of the paper is the lack of clarity in describing the physical meaning of the results. An increasing aridity index (AI) that indicates decreasing aridity is

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confusing enough. Add to that the desire to communicate changing trends in AI, and one can see how a reader becomes quickly confused. The paper would be greatly improved if it simply stated from time to time whether the results indicate that Pakistan is become more or less arid. There are also a number of places (noted below) where figure captions should contain more detail.

My second biggest concern is that the paper fails to discuss its main finding, that Pakistan has become less arid, in the context of previous studies, which largely indicate that Pakistan has recently dried. The fact that this result seems to contrast with previous investigations ought to be discussed.

More specific comments follow:

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**INTRODUCTION:** The second paragraph of the Introduction lists many studies that have evaluated Pakistan's climate. A brief synopsis of their findings (not just their methodology) seems warranted.

Furthermore, it seems a bit contradictory to end the second paragraph by saying that “no attempt has been made...to assess the changing characteristics of arid climatology. . .” and then begin the third by saying “In recent years, an increase in aridity is reported. . .” Clearly, someone has attempted to analyze Pakistani climate. Perhaps, the difference is that these other studies have considered only “shorter” time periods when studying Pakistani climate? And, yet some of the studies mentioned have analyzed multiple decades worth of data. Is what sets the present study apart the fact that it assesses changing climatic characteristics over a century? At first read, it seems that one important contribution of this work is that it tries to attribute the changes in aridity to precipitation and PET over different seasons. Perhaps this could be mentioned in the introduction.

It is also interesting that previous studies seem to suggest an increase in aridity, which

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is not what this paper finds. It might be worth stating explicitly what time periods these studies considered or what methods they used so that the reader might gain some insight into why the present study finds such different conclusions. Comparisons between this and previous work could also be embellished in the discussion/conclusions.

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METHODS: I am a bit confused as to what a moving window of 50-years with 11-year interval is. Does this mean averages consist of 11 years of data? Why are only 50 years considered in the window if a century is available? (Is it because one hopes to analyze the transient nature of the trend, e.g. Section 4.5?) This could be mentioned first in the Methods for greater clarity.

Also, it would help the reader if the paper explained how the modified Mann-Kendall test better allows one to detect trends in the presence of natural variability. Is the natural variability assumed autocorrelated?

Generally, it might aid the reader if the Methods explicitly mentioned which tests were used for which experiments (i.e. To detect significant changes over the full time period, Sen's slope was used. To evaluate variability in the trend over the course of the century, an 11-year moving average was applied to 5-decade windows of data. . .)

Moreover, for a reader less familiar with the statistical tests used, a somewhat more detailed explanation of the variables and their physical significance could be useful. As one example, it is not entirely clear what "d" and the "critical value" are in Section 3.4.

Page 11 Line 3: I think Sen's "slopes" is meant.

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SECTION 4.3 seems somewhat misleading; either that or the legend for Figure 4 is not sufficiently detailed for the reader. The text suggests only a few locations are experiencing change, while the figure (Fig 4) shows large regions colored in ways that indicate change is occurring. Do the symbols (plusses and minuses?) in Fig 4 indicate

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some type of significance? What is the difference between bold and light symbols (e.g. it is almost as if the shading was layered on top of the symbols accidentally in panel f?). The symbols should be described in the caption and perhaps made bigger (at least the minuses) for easier interpretation. Generally, throughout the manuscript, figure captions could include more details about the symbols and their significance, units, data source and/or years, etc.

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SECTION 4.4: It is a bit confusing that Figure 5 uses five aridity "trend classes" that do not correspond to the climatological classes (e.g. arid, semi-arid, etc) introduced earlier in the text. Perhaps some clarifying language here would help. Also, it is not at all obvious that positive numbers indicate decreases in aridity. Either that, or the descriptions for either the annual trends or Kharif appear to be incorrect. The physical meaning of positive and negative numbers in Figure 5 should be made very clear for the reader. This could be explained initially in Section 3.1. (i.e. that higher AI indicates more humid not arid conditions) and re-mentioned again in Section 4.4.

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SECTION 4.5 should be a bit cautious about attributing causation using words like "triggered." Figures 6 and 7 show a correspondence (correlation) between the areal change in precipitation and aridity but give no evidence of geographic overlap, which is presumably necessary for one factor to influence the other. In some ways, Figures 4 and 5 show the geographic correspondence much more clearly. That said, I do like the way Figures 6 and 7 show that trends changed in hand in hand, indicating, at least across Pakistan, that these climatic factors were influenced by the same large-scale transient controls. I would recommend that Figures 6 and 7 revisit their color choices. It is often most intuitive to use red for drying and blue for moistening. Changes in grid number clearly affect drying and moistening across Pakistan, but perhaps it is just simpler to use a more "neutral" color palette? Both the main text and the Figure

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captions could better explain whether changes in positive trend grid numbers imply a more or less arid Pakistan.

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The DISCUSSION does a nice job of mentioning previous studies that attempted to attribute changes in aridity to factors such as precipitation or temperature. However, it says little about the fact that these previous studies tended to find that Pakistan's aridity is increasing. In contrast, the current manuscript finds that a much greater spatial area is wetting compared to drying. A bit greater emphasis on and discussion of this discrepancy seems warranted.

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CONCLUSIONS: I don't see where Kharif precipitation is decreasing over a large area in the east. As far as I can tell, there is a large increase in the northeast, adjacent to a very small area of decrease.

Also, I am surprised that the conclusion fails to mention the fact that this study finds that Pakistan is becoming less dry overall. "Changes in aridity" is simply not clear enough. I would encourage the paper to say, instead, "getting wetter/drier" or "less/more arid," etc.

The last paragraph is quite vague and could be more specific for a concluding paragraph.

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#### MINOR COMMENTS

The paper should be carefully reviewed for grammar and typos.

As far as I know, "On the other hand" is the phrase typically used (rather than "on the other side").

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Page 23 Line 6: The second point should just say, "Most of the country. . ."

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., <https://doi.org/10.5194/hess-2018-642>, 2019.

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