

Anonymous Referee #3

General Comments

In this manuscript, the authors investigated spatial distribution and temporal trend of precipitation, potential evapotranspiration, and aridity in Pakistan for the 20th and 21st centuries. They used GPCC and CRU PET datasets, allowing them to conduct long-term analyses. Several non-parametric statistics such as Mann-Kendall test and Sen's slope estimator were used. These trend analyses were conducted for annual and two cropping seasons (Kharif and Rabi); most readers are not familiar with this cropping scheme but seems unique in this study. They found that some significant changes in hydrological regime in this region occurred between 1971 and 1980. I know that Pakistan is one of the highly-populated regions and its hydrological regime shift would have serious impacts, directly by altering available water and indirectly by affecting agricultural yields. In this regard, this kind of study is meaningful for planning sustainable society.

Reply

Thank you for your time and valuable comments on our manuscript. Your suggestions helped us to improve the quality of the paper. We have carefully addressed all your comments in the revision of the paper. Revised text is highlighted in red.

Comment

Nevertheless, this study obtained, in my view, quite data-specific results. In general, long-term data such as GPCC and CRU are subject to uncertainties especially in the early period when observational data so sparse. Recent studies use multiple datasets to examine the consistency and difference, in order to obtain robust results. Indeed, no range of uncertainty or confidence interval was shown for the results obtained in this study.

Reply

Thank you very much for your comment. The PET and Temperature data from 1901 are available only for CRU. Therefore, it was not possible to assess the uncertainty due to gridded data. Such analysis can be conducted in future based on the availability of data. We mentioned this as limitation of the study in end of discussion section and recommended as future work as below:

“The gridded data used in this may cause uncertainty in the estimation of aridity and its trends. Other gridded data can be used in future to assess the uncertainty in the estimated trends in aridity. Besides, different aridity assessment methods can be used to compare the results.”

Comment

The use of non-parametric statistics looks reasonable. However, the hydrological regime shift obtained by these analyses was not adequately discussed. In Discussion (Page 22 Line 5), the authors related the regime shifts to the Asian monsoon, but no sufficient evidence was presented. I guess some human impacts, such as land-use conversion and overuse of ground water, could be responsible.

Reply

The precipitation changes in the region is discussed in details in the revised manuscript. Following texts have been added for this purpose:

“The changes in temporal patterns of aridity reveal that the major shift in aridity and rainfall occurred between 1971 and 1980. Global atmospheric moisture amount is found to increase after 1973 (Ross and Elliott, 2001). An increase in precipitation in many regions of the world is observed due to the increase in global moisture content (Trenberth, 1998). The present study suggests that precipitation of Pakistan has also changed during 1971-1980 which may be due to the increase in global atmospheric moisture after 1973. This has caused a shift in precipitation and aridity in Pakistan. Machiwal et al. (2017) reported a significant change in dry season precipitation in the period 1973–1975 in the hot arid region of India. Some'e et al. (2012) assessed the change points in precipitation in the eastern part of Iran bordering Pakistan and reported a shift in annual precipitation at some stations during 1981-1982. The results collaborate with the finding of precipitation and aridity shift in Pakistan.

Many factors influence regional and local changes in precipitation including shift in monsoon circulation due to global climate change (IPCC, 2014), land use changes like the changes in forest cover and irrigated agriculture (Pielke, 2001) and aerosols in the atmosphere due to human activities (Guo et al., 2016). Studies related to anthropogenic activities on precipitation changes in Pakistan and nearby countries are very limited (Basistha et al., 2009). Previous studies suggested that global warming as the cause of the shift in precipitation pattern in the region (Duan et al., 2002;Gautam et al., 2009). The nature of the shift in rainfall regime over a large region which coincides with the increase in global atmospheric moisture suggests that global climate change may be the cause of the shift in precipitation and aridity of Pakistan.

The present study suggests that the relative influence of precipitation and temperature on aridity determines its trends in the context of climate change. Aridity may decrease due to a small increase in precipitation in the regions where the influence of precipitation is higher on aridity. The gridded data used in this may cause uncertainty in the

estimation of aridity and its trends. Other gridded data can be used in future to assess the uncertainty in the estimated trends in aridity. Besides, different aridity assessment methods can be used to compare the results.”

Comment

Finally, I felt insufficient about the lack of discussion about the impacts of aridity change on human dimensions such as agriculture. Although this is not the main topic of the manuscript, I recommend adding some discussion about the impacts of increasing or decreasing aridity in this area.

Reply

Thanks for your comment, we have added following paragraph in discussion section:

“Pakistan is mainly an agriculture-based country where a notable portion of the population is associated with the agro-based economy. Haider and Adnan (2014) reported that changes in aridity could have a severe impact on the agricultural sector of Pakistan. They showed that some regions in the northeast of the country are becoming less arid while some of the regions in the south are becoming drier. It is pertinent to mention that southern regions of the country are highly prone to droughts (Ahmed et al., 2018b). Increase in drier conditions can have a severe impact on the agricultural-based economy of the south. Similarly, the agriculture of north-eastern regions can be benefitted by the wetter condition.”

Comment

Finally, I can't recommend the manuscript as a candidate for publication in the present form. Please look my specific points. Specific points Figure 4: What the dots in the panels represent? I guess it means significance of trend, but please clarify.

Reply

Thanks for your suggestion; we have prepared larger figures with legends to improve the readability. We have increased the size of plus and minuses (to indicate the significance) on the figures. Additionally we have revised the captions of figures for easier interpretation. Furthermore, we revised the related text to make it more clear for the readers as below:

“The sen's slope is used to assess the magnitude of change in precipitation and PET for all the seasons at all the 350 grid points over Pakistan to prepare the corresponding maps as shown in Figures 4 to 6. The significance

increasing/decreasing trends estimated using MMK test at 95% level of confidence are presented using the plus (+) and minus (-) signs in the figures. The increase in precipitation indicates a wetter and the decrease a drier condition, while an increase in PET indicates a drier and decrease a wetter condition. Figure 4a shows that annual precipitation is increasing significantly over a large area in the northeast and at a few places in the far north, while it is decreasing significantly at a few places in the south and three locations near the foothills of Himalaya. It is worth to mention that precipitation is decreasing at a few locations near the foothills of the Himalaya where precipitation is highest in Pakistan (Figure 2a). The spatial distributions of the trends in annual PET are shown in Figure 4b. The annual PET in Pakistan is increasing (high evaporation rates) in the southeast corner and decreasing (low evaporation rates) at a few grid points scattered in the center and north-western parts where precipitation is usually high, and the temperature is low.

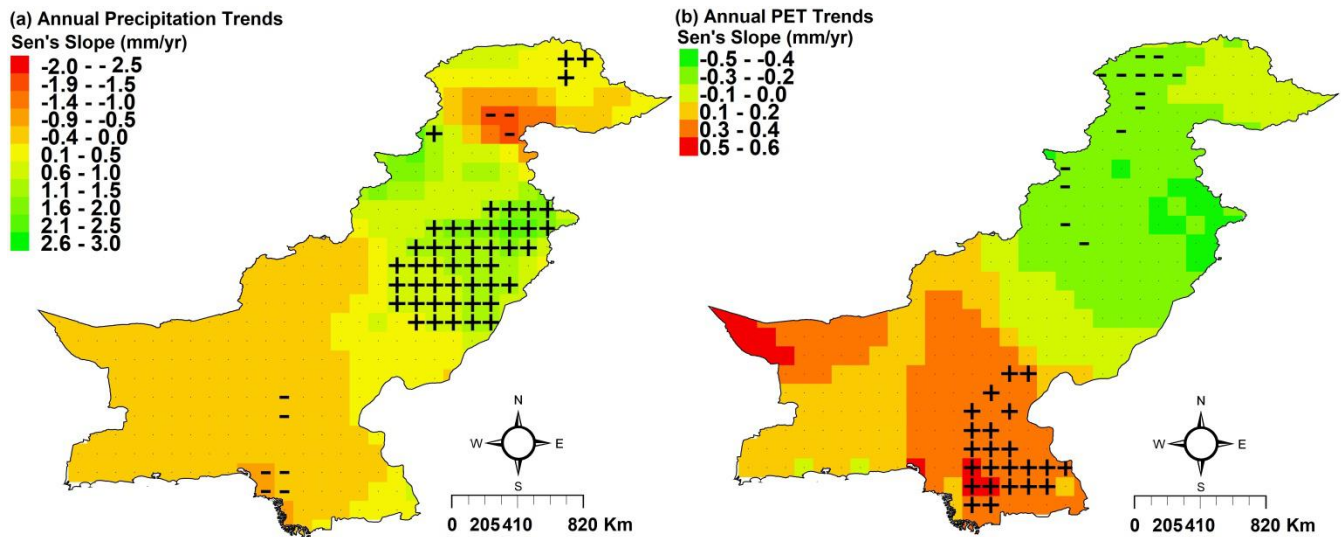


Figure 4. Spatial distribution of the trends in annual (a) precipitation and (b) PET in Pakistan estimated using modified Mann-Kendall (MMK) test. The plus (+) and minus (-) sign indicates increasing and decreasing trend at 95% confidence level respectively.

Figure 5a shows the spatial patterns in the trend of Rabi precipitation. The precipitation during Rabi is found to increase significantly at a few grid points in the north and two grid points in the east while decreasing significantly at two locations in the south. It can be observed that there is a non-significant decreasing tendency in Rabi precipitation over a large in the south. The PET in Rabi (Figure 5b) is found to increase significantly (high evaporation rates) over a large area in the southeast and the southwest, while it is not found to decrease significantly at any location.

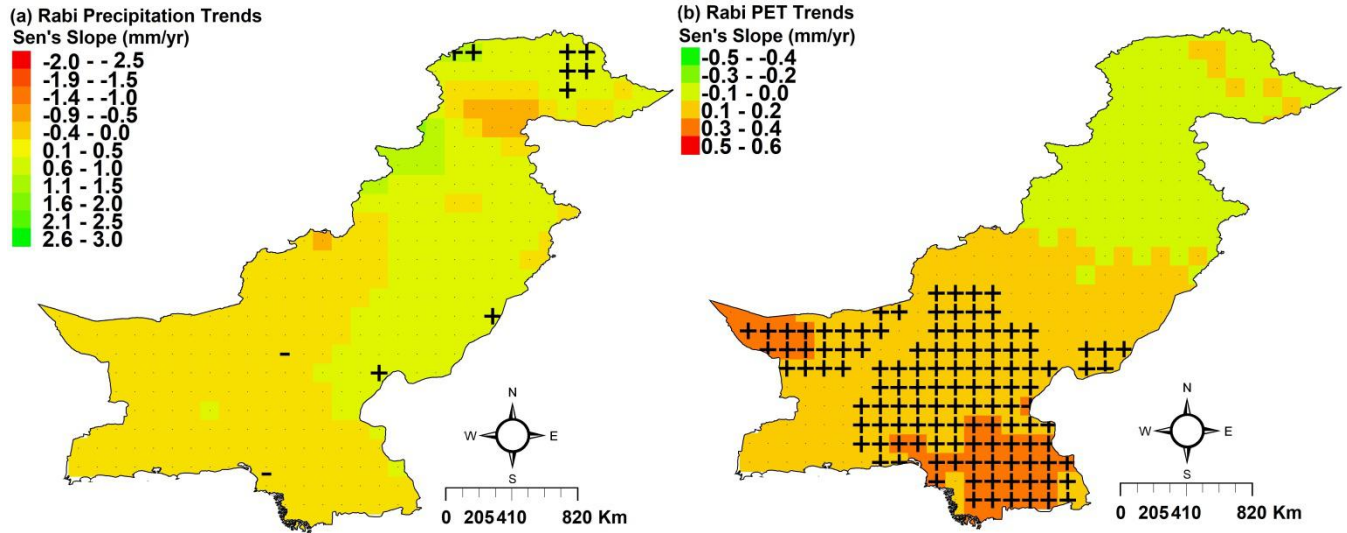


Figure 5. Spatial distribution of the trends in Rabi (a) precipitation and (b) PET in Pakistan estimated using modified Mann-Kendall (MMK) test. The plus (+) and minus (-) sign indicates increasing and decreasing trend at 95% confidence level respectively.

The Kharif precipitation (Figure 6a) is found to increase significantly in the northeast and at two grid points in the north. The significant decreasing trend in Kharif precipitation is also observed over a large area in the southwest and at a few grid points near the foothills of Himalaya. Overall, the spatial patterns in annual and Kharif precipitation trends are found very similar. The spatial distribution of PET trends in Kharif is displayed in Figure 6b. The figure shows a significant decrease in PET over a large area in the northeast and decreases at two grid points in the south.

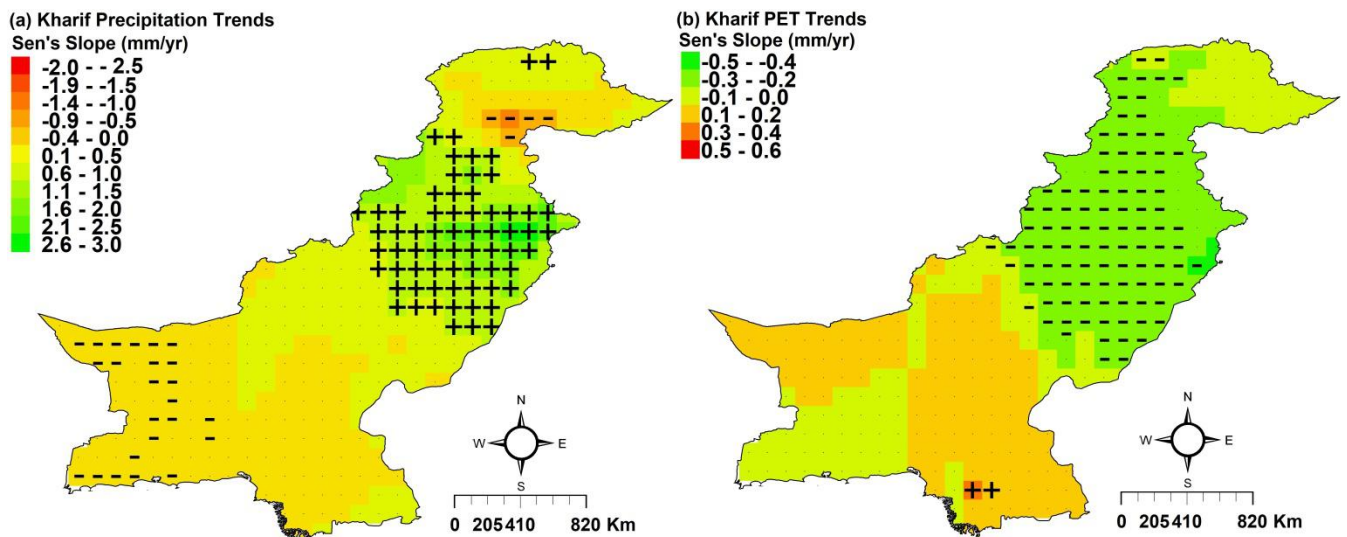


Figure 6. Spatial distribution of the trends in Kharif (a) precipitation and (b) PET in Pakistan estimated using modified Mann-Kendall (MMK) test. The plus (+) and minus (-) sign indicates increasing and decreasing trend at 95% confidence level respectively.