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Analysis of Drought Characteristics and Associated Parameters over Indus River Basin, India

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A b s t r a c t

This study is an attempt to determine the spatial-temporal pattern of meteorological droughts and exploration of the relationship between drought and elevation over Indus River basin. Gridded monthly precipitation and temperature data of 0.12°×0.12° spatial resolution for a time period of 42 years (1979–2020) is utilized. Modified Mann-Kendall test and Sen's slope method have been used to identify significant trends in the region. Drought events are identified based on Standardized Precipitation Evapotranspiration Index (SPEI) by determining of SPEI-annual and SPEI-seasonal (pre-monsoon, monsoon, post-monsoon, and winter). Results show that the trends in the drought indices have very high heterogeneity across different seasons. Overall, 13% (14%) stations show drying (wetting) trends for annual time series analysis. However, seasonally, it is found that monsoon and post- monsoon seasons have larger area in the basin with wetting trends. Moreover, pre-monsoon season have larger area with drying trends. A correlation between SPEI trends with respect to elevation is observed.

Keywords: drought, SPEI, trend analysis, elevation, Sen's slope.

1. INTRODUCTION

Drought is a natural disaster which possess a great threat to human society. The problem of water scarcity has amplified multi-folds due to coupling of effects of global warming (droughts) along with the population explosion because the available water supply is limited. Drought can

be meteorological, agricultural, and hydrological depending upon the deficiencies in precipitation, soil moisture, and stream-flow, respectively (Mishra and Singh 2010). In the recent years, the frequency of dry events has increases along with the peaks in severity as well. India is highly vulnerable to drought, occurring once in every three years from the past few decades (Mishra and Singh 2011). Drought effects various sectors especially agriculture, hence drought modelling is necessary to effectively manage the water resources. There are many indices available for quantification of drought such as Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), and Palmer Drought Severity Index (PDSI). Lot of studies has been carried out in India and abroad on drought characterization, drought risk including hazard and vulnerability incorporating various drought indices, but effect of topographic variable on drought dynamics is highly neglected. Feng et al. (2020) studied the effect of elevation on drought characteristics over Qinghai-Tibet Plateau and investigated that with the increase in elevation the wetting events are increasing. Similarly, drought hazard identification based on elevation and precipitation is carried out in Iran, showing decrease in drought hazard index with increasing elevation (Hosseini et al. 2020), neglecting the effect of temperature variable. Thus, current study aims to incorporate both the meteorological variable (precipitation and temperature) and develop a relation between drought and topographical variable (elevation). In this present study, Indian extent of Indus river basin has been considered as a case. Heterogeneity of the elevation spread over the basin makes it suitable for the study. Therefore, this study is an attempt to analysis the spatiotemporal variations of drought characteristics along with the exploration of relationship between dry events and topography in Indian extent of Indus River Basin.

2. STUDY AREA AND DATA

The drainage cover of Indus River basin in India has been considered in this study (Fig. 1). Indus River originates from China (Tibet) and flows through India, Afghanistan, and Pakistan covering a total basin area of 1.1 million km^2 out of which approximately 0.2 million km^2 is in India. Elevation spread of the basin shows high of 8489 m with lowest as 93 m. Meteorological gridded data (temperature and precipitation) of 0.12 degree spatial resolution for a period of 42 years (1979–2020) is acquired from National Centre for Medium Range Weather Forecasting (NCMRWF) under Ministry of Earth Sciences, India. Gridded elevation are extracted using SRTM 30 m resolution Digital Elevation Model (DEM) data from USGS earth explorer.

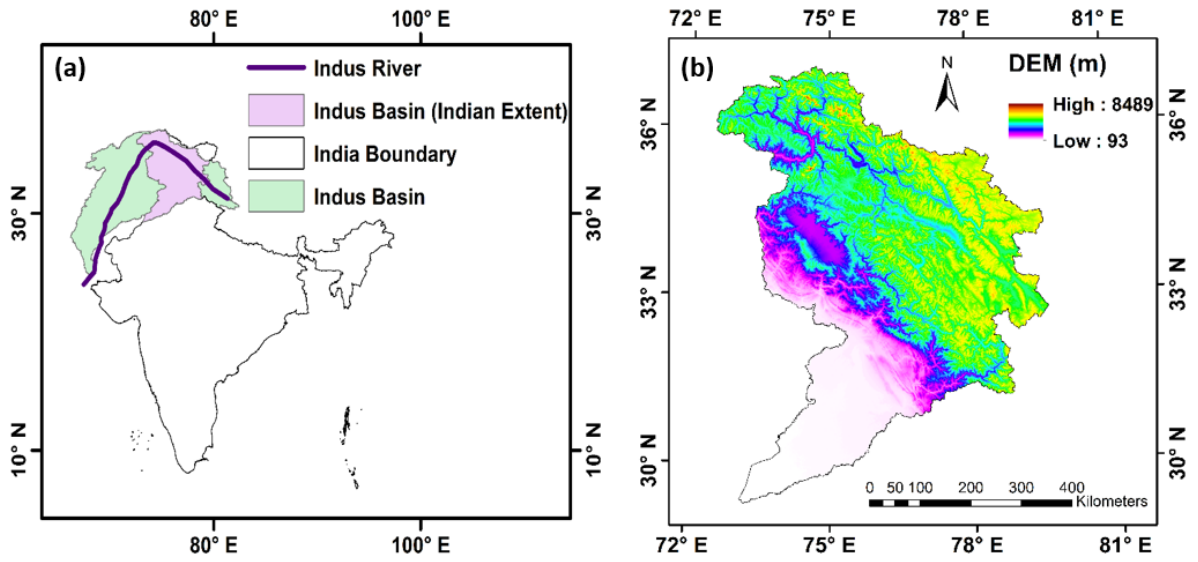

Fig. 1: (a) Study area of Indus basin, and (b) Digital Elevation Model (DEM).

3. METHODS

Standardized Precipitation Evapotranspiration Index (SPEI) is used to quantify the drought in present study. The analysis is carried out annually (June–May) and seasonally (monsoon June–September, post-monsoon October–November, winter December–February and pre-monsoon March–May). Therefore, SPEI 2, 3, 4, and 12 is computed for the entire region. SPEI is based on climatic balance equation, depending upon precipitation and Potential Evapotranspiration (PET) to identify the moisture deficiency. Hargreaves method of PET estimation has been employed, which is good option when data available is limited. Computation of SPEI and PET is done in R software using Package "SPEI". In order to detect trend in the time series, a non-parametric test called modified Mann-Kendall test at 5% significance level is used. Drawback of Mann-Kendall test includes that data has to be free from serial correlation otherwise the false rejection of hypothesis may happen, while the above limitation is rectified in modified Mann-Kendall test which is applied in R software using Package "modifiedmk". The rate at which trend increases or decreases is estimated by Sen's slope. It provides magnitude of the trend representing positive (negative) for increasing (decreasing) trend. To represent the spatial variation of Sen's slope (SPEI trends) kriging technique is applied, which is an interpolation method utilizing input as a point data and then converting into a smooth raster image.

4. RESULTS

4.1 Analysis of SPEI trends

Trend analysis on SPEI annual and seasonal time series of 1956 gridded stations have been carried out over the entire region (Fig. 2). Increasing (decreasing) trend corresponds to increase in wet (dry) events.

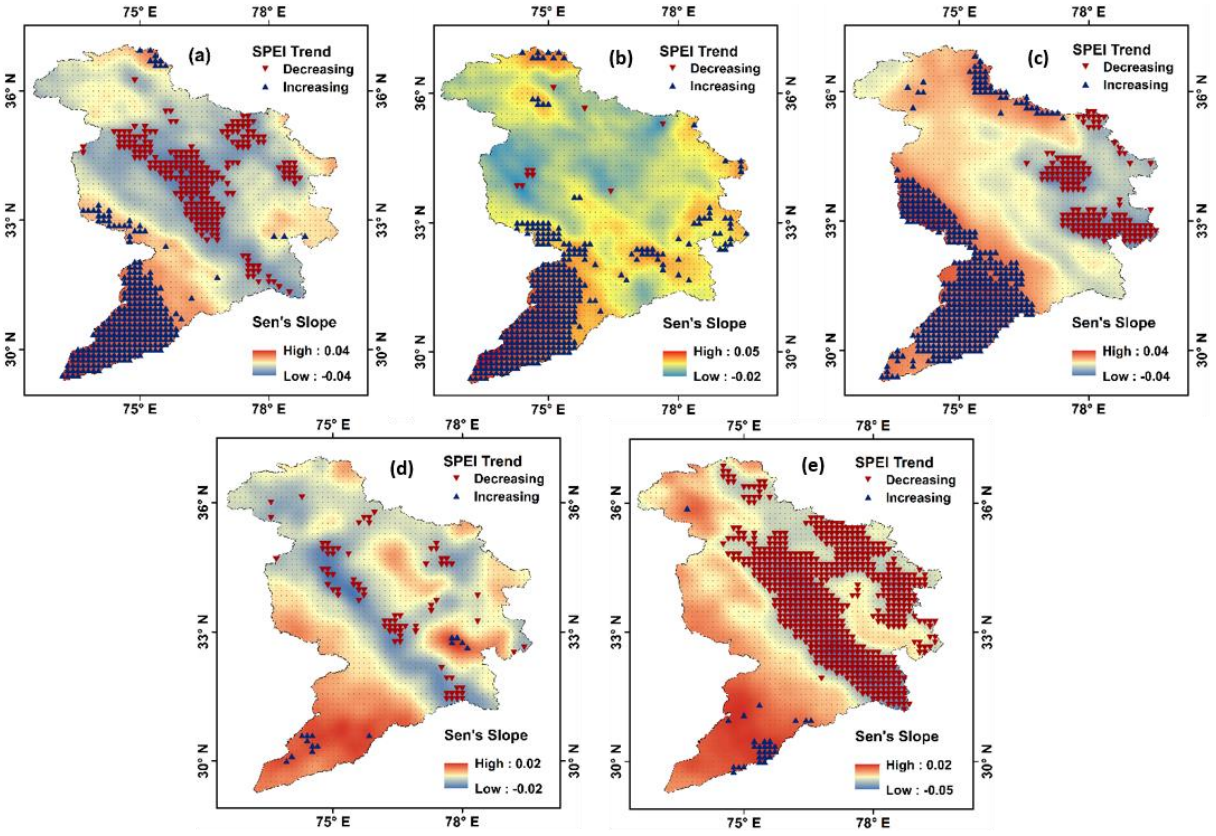

Fig. 2. Annual and seasonal distribution of SPEI trend: (a) annual, (b) monsoon, (c) post-monsoon, (d) winter, and (e) pre-monsoon.

Results show that the trends in the drought indices have very high heterogeneity across different seasons. Overall, 13% (14%) stations show drying (wetting) trends for annual time series analysis. However, seasonally, it is found that monsoon and post-monsoon seasons have larger area in the basin with wetting trends. Moreover, pre-monsoon season have larger area with drying trends, whereas, majority of the stations in winter season shows no trend.

4.2 Elevation dependence of SPEI trends

Figure 3 illustrates the relationship plot between Sen's slope of SPEI trend and elevation. Overall, it is observed that approximately up to 2000 m, wetting trends are present. Later on, with the increase in elevation the trends shift from wetting to drying corresponds to increase in dry events. Moreover, at very high altitudes above 6500 m, trends again apparently seems to decrease the drying magnitude and may attain an increasing trend.

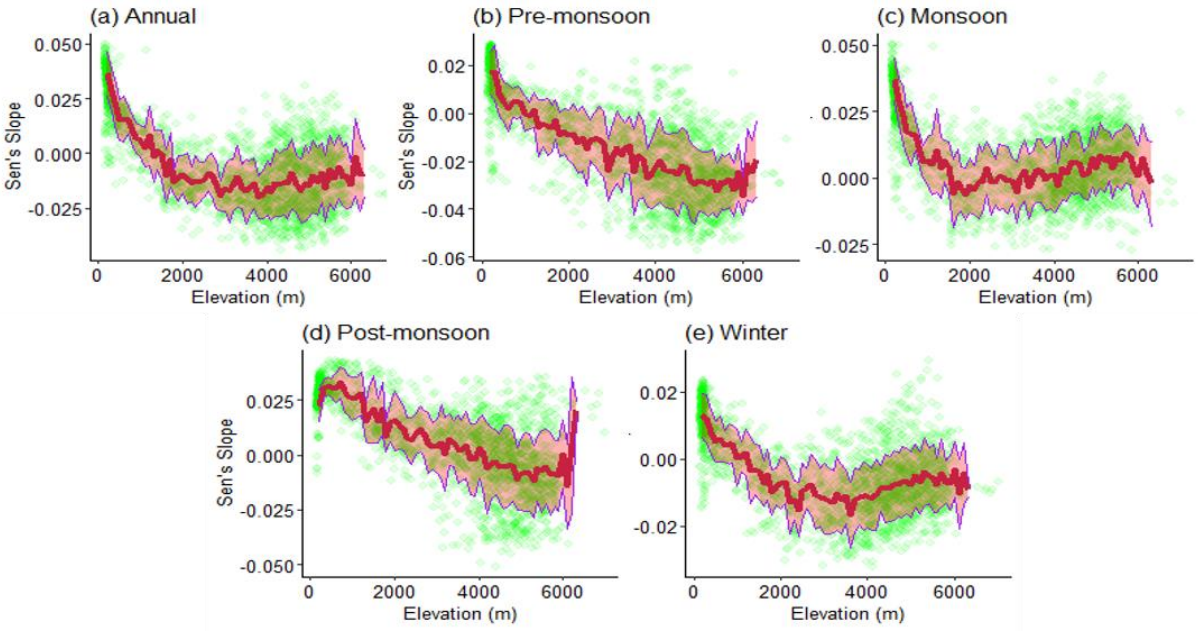

Fig. 3 Annual and seasonal relationship between SPEI trends and elevation; scatter points in green colour represents the Sen's slope of 1956 gridded stations with respect to elevation; red smooth line indicates the average of Sen's slope at every 100 m elevation interval along with the shaded area illustrating standard deviation.

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