Modified Mann-Kendall (MMK) trend test

This study implemented MMK trend test to evaluate the spatial drought trend characteristics over four river basins of south India from 2003-2016. The MMK trend test is performed as follows,

Consider a sequence X_T and divide it by the mean of this series to obtain a new series X_t. Null hypothesis (H_0): no trend in the series over time. Alternate hypothesis (H_1): existence of increasing or decreasing trend.

The trend estimator β of the rank for the new series is calculated as:

$$\beta = median\left(\frac{x_i - x_j}{i-j}\right) \quad 1 \leq i < j \leq n \tag{1}$$

Where $\beta > 0$ represents upward trend and $\beta < 0$ represents downward trend.

If the trend part T_t of the new series X_t is linear then trend part is removed to obtain the stationary series Y_t.

$$Y_t = X_t - T_t = X_t - \beta \times t \tag{2}$$

The rank corresponding to series Y_t is calculated and its corresponding autocorrelation coefficient r_i is obtained.

$$r_i = \frac{\sum_{k=1}^{n-i}(R_k - \bar{R})(R_{k+i} - \bar{R})}{\sum_{k=1}^{n}(R_k - \bar{R})^2} \tag{3}$$

where $\bar{R}$ is the average rank and R_i is the rank of y_i.

The variance $V(S)$ of the trend statistic S of autocorrelation series is obtained as follows:

$$V(S) = \eta \times \frac{n(n-1)(2n+5)}{18} \tag{4}$$

$$\eta = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{i=1}^{n-1}(n-i)(n-i-1)(n-i-2)r_i \tag{5}$$

The test statistic Z is calculated as

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S-1}{\sqrt{V(S)}} & S < 0 \end{cases} \tag{6}$$

If $|Z_s| < Z_{0.05/2}$ for a given significance level α, then the hypothesis (H_0) is accepted, otherwise rejected.

Standardized Precipitation Evapotranspiration Index

Several drought indices were established to evaluate droughts by integrating the climate variables like precipitation, soil moisture, runoff, temperature, and evapotranspiration. SPI is widely used to evaluate the meteorological drought that require only precipitation dataset to compute drought events. As SPI considers only one variable to quantify the drought, it may not reflect the true water deficit in the region. Vicente-Serrano et al. [1] developed a new index named Standardized Precipitation Evapotranspiration Index (SPEI) that considers potential evapotranspiration (PET) along with precipitation, considering all the advantages of SPI. SPEI can be evaluated from 1 to 48-month time scale, representing short-term to multiyear water deficit that result in agricultural, hydrological and meteorological droughts [2-5]. In this study SPEI is evaluated at 12-month timescale. For the SPEI calculation, first the difference between precipitation and PET is calculated.

$$D_i = P_i - PET_i \tag{7}$$

where, D_i = surplus or deficit in the catchment for the i^{th} month.

For the computation of PET, the most widely used equations are Penman-Monteith, Hargreaves and Thornthwaite. Due to scarcity of data Penman-Monteith equation is difficult to use. Therefore, because of its simplicity and lower data requirement, Hargreaves method is adopted to evaluate PET in this study. The calculated D_i values were then accumulated to a 12-month scale. Then the probability distributions were fitted to the aggregated series and best distribution is selected using L-moments method. The cumulative distribution function of the selected distribution is then normalized to compute the SPEI series. Then the method of run concept is adopted to calculate the drought characteristics like severity and duration.

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