Meteorological drought trend analysis in northern Karnataka

Trend Analysis of Seasonal Drought in Northern Karnataka

ABSTRACT

Trend analysis of climatic data is often carried out in water resources management studies in orderto understand its distribution over a given region. This paper presents an analysis of trends in meteorological drought of 12 districts in the northern part of Karnataka state, India over the period 1991–2020. Trends in the 3-month timescale standardized precipitation index (SPI-3) were analyzed using the Mann-Kendall (MK) trend test and Sen's slope estimator for the *Kharif* season. Results obtainedshowed an increasing trend of droughts in four districts however, the trend in most of the districts were not statistically significant. The findings are in conformity with the trend of the declared area under drought (AUD) by the state government for the study area. The findings of this work are useful for a better understanding of regional drought trends and also for establishing effective water resources management policies.

Keywords: Trend analysis, Mann Kendall Test, Meteorological drought, SPI

1. INTRODUCTION

Drought is one of the most complex and poorly understood natural hazards occurring worldwide (Wilhite, 2000). It is described as a prolonged, continuous lack of water in meteorological, hydrological, and agricultural systems. This phenomenon occurs in all climate zones irrespective of the amount of precipitation they receive (Mishra and Singh, 2010). Water consumption has increased globally as a result of the world's population growth, industrialization, and agricultural expansion (Amarasinghe*et al*. 2007). It is believed that as a result of climate change, the sustainable limits on the use of water resources have been exceeded, eventually resulting in manmade droughts (Van Loon *et al*. 2016). However, there has also been an increase in precipitation (Westra*etal*. 2013, Donat*et al*. 2016). It is anticipated that the unequal distribution of precipitation changes will increase the frequency and intensity of droughts in many regions.

Droughts have an impact on food production and plant growth, and can seriously jeopardize food security (Zhang *et al*. 2017). Karnataka state has experienced numerous droughts in past years, some of which have severely reduced food production. Several studies conducted across the Indian subcontinent have reported an increase in the frequency of droughts as a result of climate change (Alamgir*et al*., 2015; Bisht*et al*., 2019). There are some established literatures on trend analysis of droughts in Karnataka (Bharath and Venkatesh,2022). Pathak and Dodamani (2020) observed asignificant number of annual and seasonal droughts using Mann–Kendall test and SPI over the Ghataprabha River Basin, India. Mallya*et al*. (2016) investigated trends and variability in the droughts over the Indian monsoon region using IMD datasets. Bisht*et al*. (2019) and Aadhar and Mishra (2018) utilized SPEI and found an increasing trend in the occurrence, duration and severity of droughts. Rajput *et al.* (2023) investigated rainfall, temperature and relative humidity for a meteorological station in the NCR region and found a significant positive trend in relative humidity for the period 1990-2020. A comprehensive agriculture plan can be developed to protect crops and increase crop productivity with the aid of district-level climatic variable trend evaluation (Khavse and Chaudhary, 2022). The aforementionedstudies concentrated on the annual rainfall trend across different river basins in Karnataka. Only very few studies carried out at the district level by using annual time series of meteorological drought indices.

This studywas intended for the understandingof draught trend in the northern part of the Karnataka state. The objective of the present study was to analyze the trend of meteorological drought using the Kendall test and Sen's slope test. The results of trend analysis will be compared with the area under drought (AUD) declared by the state government. This research will contribute to improving our understanding of the frequency and variability of drought in India. The scientific community would be encouraged to use a creative method to comprehend the underlying frequencies for more than just the drought in this study.

2. METHODOLOGY

2.1 Study area and data utilized

The study area (Figure 1) selected for the present study was the Karnataka state of India which is one of the most drought-affected states in the country with more than 60% of land falling under dry tracts. This has a geographical extent between 11° 30' to 18° 30' North latitudes and 74° to 78° 30' East longitudes and covers an area of 19.1 M ha, which accounts for 5.8% of the total area of India. The majority of the agriculture in the state is rainfed. The spatiotemporal pattern of the southwest monsoon plays a critical role in determining the *Kharif* season crop production. The northern part of the state is often observed to be under drought due to deficit rainfall and other physiographic features. For the meteorological drought trend analysis, India Meteorological Department (IMD) gridded monthly precipitation data at 0.25°×0.25° was utilized. This data was aggregated for each district to get the district-wise analysis.

2.2 Calculation of SPI

The Standardized Precipitation Index (SPI) was originally developed by McKee et al. (1993). The SPI was calculated for 3-month timescale for the *Kharif* crop growing season using IMD datasets for the Karnataka state for the period 1990 to 2020 for each district. The long-term record was fitted to a probability distribution, which is then transformed intoa normal distribution so that the mean SPI for the location and desired period is zero (Edwardsand McKee, 1997).

The gamma distribution is defined by its probability density function in Equation (1):

$$g(x) = \frac{x^{\alpha-1}.e^{-x/\beta}}{\beta^{\alpha}.\Gamma(\alpha)} \text{ for } x > 0 \quad (1)$$

where α > 0 is a shape parameter, β > 0 is a scale parameter, x is the precipitationamount, and $\Gamma(\alpha)$ is the gamma function which is defined in Equation (2):

$$\Gamma(\alpha) = \int_0^\infty y^{\alpha-1}.e^{-y}dy \quad (2)$$

For fitting the distribution to the data, *α,* and *β* be estimated as (Edwards and McKee,1997):

$$A = \log\bar{x} - \frac{1}{n}\sum_{i=1}^{n}\log x \quad (3)$$

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (4)$$

$$\beta = \frac{\bar{x}}{\alpha} \quad (5)$$

$$SPI = \frac{x_{ij} - x_{imean}}{\sigma_i} \quad (6)$$

The calculated SPI-3 was further utilized for trend analysis.

2.3 Trend analysis

The trend analysis was performed using two methods namely the Mann Kendall test and Sen's slope estimator. The MK test is used to identify the monotonic trend present in the data while the Sen's slope determines the magnitude of the trend slope. The trend analysis was performed at 12 districts of Karnataka using the computed SPI-3 for the period 1991–2020.

2.3.1 Mann Kendall test

The non-parametric Mann-Kendall test (Mann 1945; Kendall 1975) is a popular technique employed to detect monotonic trends in a series of environmental and climate data. The null hypothesis, H0, is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, HA, is that the data follow a monotonic trend. The monotonic trend can be upward or downward depending upon the increase or decline of the variable for a time period under consideration. The Mann-Kendall test statistic is calculated according to:

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn\left(X_j - X_k\right) \quad (7)$$

$$sgn\left(X_j - X_k\right) = \begin{cases} +1 \; if \; X_k > X_j \\ 0 \; if \; X_k = X_j \\ -1 \; if \; X_k < X_j \end{cases} \quad (8)$$

where X_j and X_k show the data at times j and k respectively and n is the total time period of the data used. A positive value of S (S>0) indicates a variable continuously increasing with time while a negative value of S shows a decreasing trend.

The mean of S is zero and the variance σ^2 is

$$\sigma^2 = \frac{\left\{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j\left(t_j-1\right)\left(2t_j+5\right)\right\}}{18} \quad (9)$$

Where, where p is the number of the tied groups in the data set and t_j is the number of data points in the j^{th} tied group. The statistic S is approximately normally distributed provided that the following Z-transformation is employed

$$Z = \begin{cases} \frac{S-1}{\sigma} \; if \; S < 0 \\ 0 \quad if \; S = 0 \\ \frac{S+1}{\sigma} \; if \; S > 0 \end{cases} \quad (10)$$

2.3.2 Sen slope test

This method proposed by Hirsch et al. (1982) computes the magnitude of the slope of the trend and intercept. A set of linear slopes is calculated as Equation (11)

$$d_k = \frac{X_j - X_i}{j - i} \quad \text{For } 1 \leq i < j \leq n \qquad (11)$$

where d is the slope, x_j and x_i are data measurements at time j and i respectively and n is the number of data.

Sen's slope is then calculated as the median from all slopes: $b = Median\ d_k$

The intercepts are computed for each timestep t as given by $a_t = x_t - b \times t$ (12)

and the corresponding intercept is the median of all intercepts.

2.4 Declared Percentage area under drought (AUD)

The districts declared as drought affected by state government in the northern Karnataka were identified and the total AUD was calculated for the region by adding the areas of the affected districts for each year. The percentage AUD was then calculated by dividing with the total area of the region

3. Results and discussion

The linear trend plots of SPI-3 were analysed for 12 districts of northern Karnataka and displayed in Figure 2. It is evident from the Figure that the SPI did not follow a uniform trend as such for all the districts, however, some districts like Belgavi, Dharwad, Bidar and Haveri followed a decreasing trend. Other districts recorded an upward trend. Here it was observed that the SPI value which ranges from -3 to +3 varies significantly from year to year as shown by sharp peaks. This variation may have resulted in a non-uniform trend of the data.

The SPI-3 data for these districts were analysed using the Kendall test and trend results are presented in Table 1. From the perusal of the table, it is visible that only 4 districts namely Belagavi, Bidar, Dharwad and Haveri recorded a decreasing trend of SPI-3 with MK test Z values of -0.642, -0.321, -0.856 and -0.178 respectively. A positive trend of SPI-3 was observed for other districts for the study period. However, for all the districts the trend test exhibited a p-value more than 0.05 (p>0.05) indicating the non-existence of a significant monotonic trend of meteorological drought at a 5% level. The SPI-3 data showed no significant trend, implying no considerable variation in the meteorological drought conditions during the study period.

After the identification of the trend using the MK test, the Sen slope was estimated to quantify the slope magnitude. The Sen slope magnitude varies significantly among districts indicating the presence of a trend in the districts. The trend is called an increasing or positive trend when the Sen slope value is positive and vice versa. Districts Belagavi, Bidar, Dharwad and Haveri recorded a decreasing trend of SPI-3 with Sen’s slope values of -0.016, -0.006, -0.014 and -0.004 respectively. Results of the Sen’s slope test displayed in the spatial map (Figure 1) portray similar results as the MK test with an increasing trend for 8 districts and a decreasing trend for 4 districts.

Here, the positive trend means the value of SPI is increasing year on year indicating more rainfall in the district thereby less stressed conditions of meteorological drought. In opposite the negative or decreasing trend means the values of SPI are decreasing indicating a lesser amount of rainfall and more stress due to meteorological drought.

The percentage area under drought (AUD) for the northern Karnataka region declared by the state government also exhibited no significant trend during the study period as shown in Table 1. Therefore, it could be said that the trend of meteorological drought using SPI-3 was consistent with the declared drought events for the region.

Table 1 Men Kendall and Sen slope trend test results for northern Karnataka districts

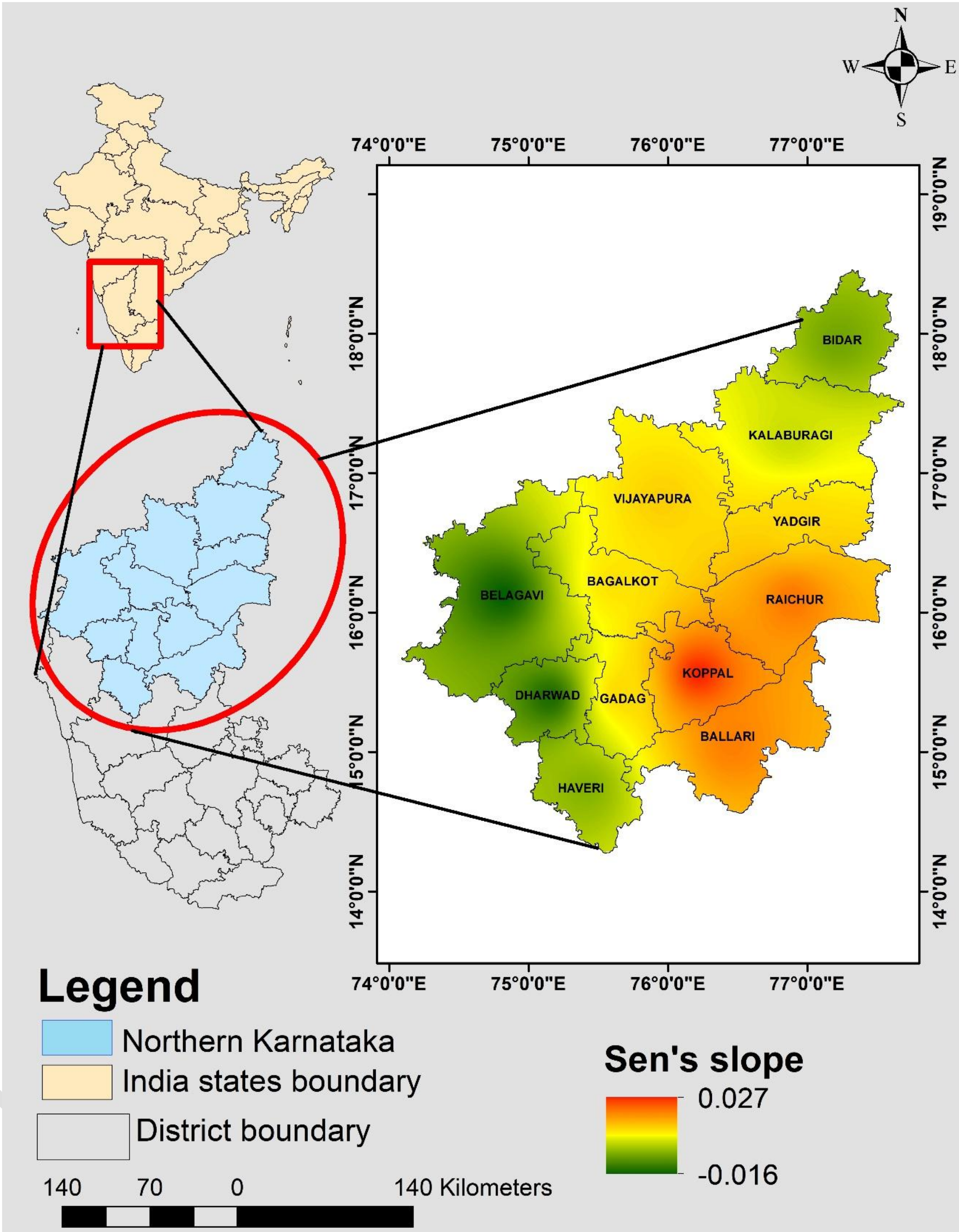

Figure 1. Spatial map of Sen’s slope trend magnitude

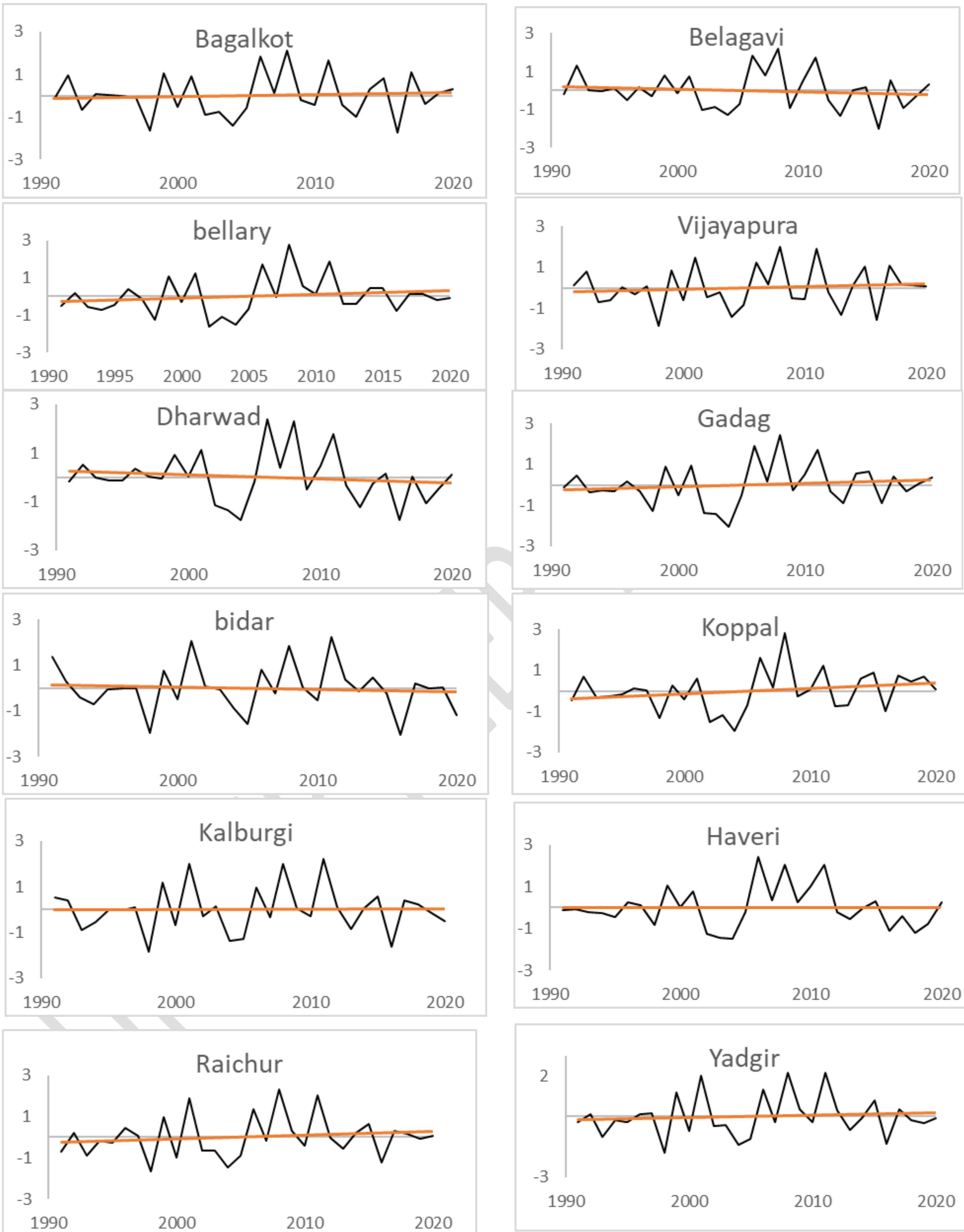

Figure 2. SPI-3 trend of Northern Karnataka districts

CONCLUSION

Based on historical rainfall records the meteorological drought trend was examined using Man Kendall and Sen slope tests for 12 districts in northern Karnataka state. The outcomes of the tests revealed a decreasing trend for four districts however, it could not observe any significant trends magnitude in the timeseries data of SPI-3 for *Kharif* season during the investigation period. The meteorological trend was observed similar to the trend of the declared area under drought for the northern Karnataka region during the study period. It could be concluded that only SPI is not suitable for drought characterization but for trend analysis.

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