**Original Research Article**

# Investigating Spatiotemporal Variation of Evapotranspiration Trends using Non Parametric Statistical Techniques across North Eastern Dry Zone of Karnataka, India

**ABSTRACT**

This paper examines the temporal variation of ETo over the 10 main subdistricts of the North Eastern Dry Zone of Karnataka,, India, during the period 1982-2022 using non-parametric statistical analysis. The findings show that ETo variability also exhibits diverse spatial and temporal characteristics in the study area. February month shows the highest decrease in the values (ZMK -2.33 to -1.72, p<0.05). Winter and summer shows highly significant decreasing trends, Manvi showing the maximum decreasing trend in winter (ZMK = -2.57, p < 0.01) and Raichur in summer (ZMK = -2.89, p < 0.01). Sen's slope estimates show average decrease of -0.18 to -0.15 mm/month in winter and an average value of -0.246 mm/month in summer. For monsoon and post monsoon, the trends are weaker and not significant ranging from -0.05 to 0.03 mm/month. Yearly changes reveal slightly negative values (-0.12 to -0.04 mm/month). Spatial interpolation of the ETo changes is done using ArcGIS's inverse distance weighting (IDW) method to show the regional differences. An increase in air temperature results in the rise in the trends in some months while, a decline in wind speed may be reason in other region. These findings are useful in understanding the ETo dynamics in the region and its relation to water and agriculture. More studies are required to understand why there was a reduction in wind speed as well as to develop individual water management strategies that will adapt to these changes.

*Keywords: Evapotranspiration, Trend Analysis, Mann-Kendall test, Spearman's Rho test, Water Management*

## 1. INTRODUCTION

Under changing climatic conditions, water management in semi-arid areas presents great difficulty. More frequent and severe dry spells result from the increased variability of precipitation patterns as well as occasional extreme rainfall events thereby making water availability unpredictable. Increased evapotranspiration rates due to rising temperatures further reduce water availability and increase crop water requirements (Zamani *et al.,* 2022). Evapotranspiration is one of the important components of the hydrological cycle, which generally varies in the spatial and temporal pattern due to climate change, i.e., anthropogenic factors and global warming due to the increased radiation and change in climatic parameters (IPCC 2007). The understanding of the relationship between ecosystem dynamics and the water cycle, particularly in arid and semi-arid environments where water is a scarce resource due to its erratic and intermittent presence, depends heavily on this kind of research[27-30]. Furthermore, investigation of climate change effects on the variables of evapotranspiration (ET) can be effective in determining appropriate adaptation strategies form mitigating the probable damage from these effects (Liu *et al.*, 2018).

In recent years, many studies on the spatiotemporal trends and their magnitude in meteorological (rainfall, evapotranspiration, temperature, humidity, etc.) and hydrological (streamflow) time series data have been carried out recently worldwide using both parametric (simple linear regression) and non-parametric (Spearman's Rho, MK, MMK,) tests (Machiwal *et al.*, 2019; Achite *et al.*, 2022). Ashraf *et al.* (2023) assessed the variability of the drought using trend analysis. The long−term investigation of hydro−meteorological parameters was carried out by Toma *et al.* (2023) show that water resources vary over time with respect change in the trends. Parametric trend tests are more powerful than non-parametric ones; however, non-parametric tests are more robust and flexible. In comparison, non-parametric trend tests require only that the data be independent and can tolerate outliers in the data. On the other hand, they are insensitive to the type of data distribution. The Mann-Kendall (MK) and Spearman's Rho (SR) tests are examples of non-parametric tests that are applied for the detection of trends in many studies (Goutali and Chebana, 2024).

The ability to identify monotonic trends was demonstrated by comparing the MK and SR test powers and their respective outcomes. Recent research on climate change has mostly concentrated on long-term variations in precipitation and temperature. Less emphasis has been paid to ET, the third most significant climatic element regulating the energy and mass exchange between Earth's terrestrial ecosystems and the atmosphere (Chen et al., 2006). The Penman-Monteith method, considered the standard by FAO, provides more accurate $ET_o$ estimates across a wider range of climates, but requires more input data including solar radiation, air temperature, humidity, and wind speed. However, when limited meteorological data is available, the Hargreaves method is used estimating reference evapotranspiration ($ET_0$), which is the rate of evaporation from a well-watered grass surface. It is calculated based on readily available temperature data, making it particularly useful in areas with limited meteorological data.

The aim of this study was to investigate the spatiotemporal trends on $ET_o$ time series over Northeastern Dry Zone of Karnataka, India. i) to analyze the temporal trend in monthly, seasonal and annual evaporation ($ET_o$) time series data using the MK and SR tests; (ii) to detect the magnitude (slope) of trend line in monthly, seasonal and annual evaporation ($ET_o$) and (iii) to analyze the spatial pattern of trends and its magnitude in monthly, seasonal, and annual evaporation ($ET_o$) using The inverse distance weighting (IDW) in ArcGIS software.

## 2. MATERIAL AND METHODS

### 2.1 Study Area

This study investigates the variability in rainfall time series for a 41-year period (1982–2022) in the northeastern dry zone of Karnataka, India. Three districts of Karnataka fall under NEDZ. The study region of NEDZ is located between 76° 10' E to 77° 30' E and 16° 0' N to 17° 30' N and falls in Yadgir, Raichur, and Gulbarga districts and 10 main subdistricts of Karnataka, newly formed subdistricts left (Sirwar, Arakera and Shahabad) (Fig. 1). It has an average elevation of 438 meters. The study region experiences four seasons: summer from March to May, followed by the southwest monsoon from June to September, post-monsoon from October to December, and then dry winter until February. The average rainfall is less than 650 mm. The temperature during the summer ranges from 31°C to 42°C; during the monsoon, from 28°C to 32°C; and in the winter, from 15°C to 26°C. Crop husbandry, animal husbandry, forests, pasture, and the domestic sector are interlinked sub-systems of the village ecosystem (Nautiyal et al., 2018). The summary of the geographic conditions for subdistricts of study region given in Table 1.

### 2.2 Data

The shape file for study area mapping and interpolation obtained from the Karnataka State Remote Sensing Applications Centre (KSRSAC). The ERA5_AG provides comprehensive, high-resolution climate data that is particularly relevant for agricultural studies. Its global coverage and consistent methodology make it an excellent choice when local observational data is limited or unavailable in the study region. The ERA5-AG daily maximum and minimum temperature dataset with a native horizontal resolution of about 9.6 km (released on a regular 0.1◦ x 0.1◦ grid) by replaying the land component of ERA climate reanalysis was obtained from https://app.climateengine.org/climateEngine (ClimateEngine.org) for 41 years (1982-2022) for all subdistricts.

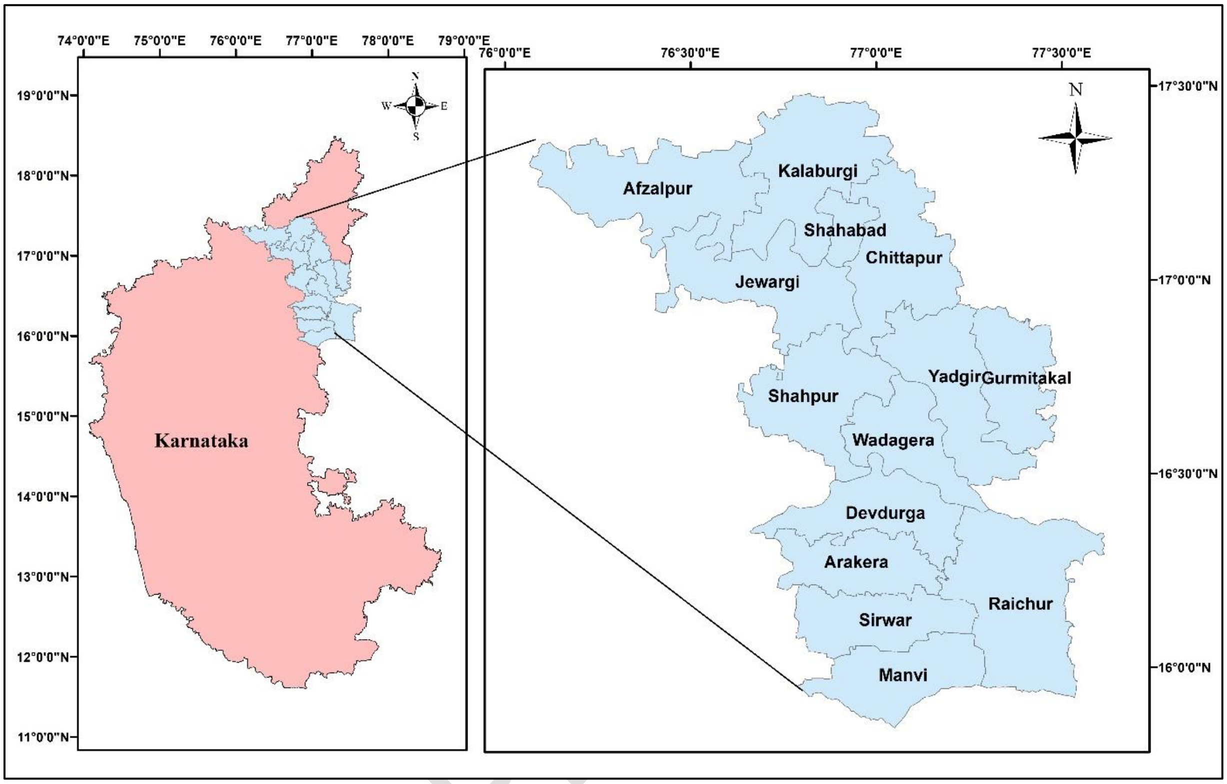


**Fig. 1. Study area map**

**Table 1. The summary of the geographic conditions for subdistricts of study region**

| Subdistrict | | Geographical characteristics | | |
|---|---|---|---|---|
| No | Name | Elevation (m) | Latitude | Longitude |
| **1** | Afzalpur | 480 m | 17.2026° N | 76.3578° E |
| **2** | Chitapur | 420 m | 17.1182° N | 77.0830° E |
| **3** | Devadurga | 398 m | 16.4235° N | 76.9355° E |
| **4** | Gulbarga | 454 m | 17.3297° N | 76.8343° E |
| **5** | Yadgir | 389 m | 16.7487° N | 77.1309° E |
| **6** | Jewargi | 493 m | 17.0114° N | 76.7769° E |
| **7** | Manvi | 361 m | 15.9951° N | 77.0478° E |
| **8** | Raichur | 407 m | 16.2160° N | 77.3566° E |
| **9** | Sedam | 594 m | 17.1784° N | 77.2873° E |
| **10** | Shahapur | 428 m | 16.6957° N | 76.8432° E |

## 2.3 Estimation of Reference Evapotranspiration ($ET_0$) by Hargraves Method

In this study, the Hargreaves method was used for estimation reference evapotranspiration ($ET_0$). Hargreaves computes the monthly reference evapotranspiration ($ET_0$) of a grass crop based on the original

Hargreaves equation (1994). The Hargreaves method requires only measured values of maximum and minimum temperatures and thus, recommended for general use. The equation given by

$$ET_0 = 0.0023 \times RA \times (T°\text{C} + 17.8) \times TD^{0.50}$$

In which, $ET_0$ and RA = same units of equivalent water evaporation; RA = extraterrestrial radiation; TD = Tmax - Tmin (mean maximum minus mean minimum temperatures in degrees Celsius); and T °C is (Tmax + Tmin)/2.

## 2.4 Trend Analysis

In this study, to analyze the possible trends in reference evapotranspiration ($ET_0$), two non-parametric tests for trend detection were used: Mann–Kendall (MK) test and Spearman's rho test (SR) for the assessment of the statistical significance (Mann, 1945; Kendall, 1975; Lehmann, 1975), Sen's slope estimator test (S) for the evaluation of the slopes of the trends (Sen, 1968).

### 2.4.1 Mann-Kendall Trend Test

The Mann–Kendall (MK) statistical test is non-parametric test, has been widely used to quantify the significance of trends in hydro meteorological time series. The Mann–Kendall (Mann, 1945; Kendall, 1975) is is based on the correlation between the ranks and sequences of a time series. For a given time series {Xi, i = 1, 2…, n}, the null hypothesis H0 assumes it is independently distributed, and the alternative hypothesis $H_1$ is that there exists a monotonic trend. The test statistic S is given by:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(P_j - P_k) \quad (1) \qquad \text{…. (1)}$$

$$\text{where, } \text{sgn}(P_j - P_k) = \begin{cases} 1 \text{ if } (P_j - P_k) > 0 \\ 0 \text{ if } (P_j - P_k) = 0 \\ -1 \text{ if } (P_j - P_k) < 0 \end{cases} \qquad \text{…. (2)}$$

In which, n is the number of data and P is the observation at times k and j (with j > k). The variance of S is computed

$$\text{Var}(S) = [n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)]/18 \qquad \text{…. (3)}$$

Where, $t_i$ is the number of ties of extent i and m is the number of tied rank groups. For n larger than 10, the standard normal ZMK test statistics are computed as the Mann–Kendall test statistics as follows;

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0, \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{for } S < 0 \end{cases} \qquad \text{…. (4)}$$

By applying a two-tailed test, for a specified significance level α, the significance of the trend can be evaluated.

### 2.4.2 Spearman's rho Test

As a comparison to the Mann-Kendall test, Spearman's rho test (SR) is another rank-based nonparametric technique for trend analysis (Lehmann, 1975). In this test, which assumes that time series data are independent and identically distributed, the null hypothesis ($H_0$) again indicates no trend over time; the alternate hypothesis ($H_1$) is that a trend exists and that data increase or decrease with $i$ (Yue *et al*., 2002). The test statistics Rsp and standardized statistics Zsp are defined as

$$R_{sp} = 1 - \frac{6\sum_{i=1}^{n}(D_i - i)^2}{n(n^2-1)},$$

$$Z_{sp} = R_{sp}\sqrt{\frac{n-2}{1-R_{sp}^2}} \qquad \text{…. (5) \& (6)}$$

In these equations, $Di$ is the rank of $i^{th}$ observation, $I$ is the chronological order number, $n$ is the total length of the time series data, and Zsp is Student's $t$-distribution with ($n$−2) degree of freedom. The positive values of Zsp represent an increasing trend across the hydrologic time series; negative values represent the decreasing trends. The critical value of $t$ at a 0.05 significance level of Student's $t$-distribution table is defined as $_{(n-2,1-\alpha/2)}$. If $|Z\text{sp}|>_{(n-2,1-\alpha/2)}$, ($H_0$) is rejected and a significant trend exists in the hydrologic time series.

### 2.4.3 Sen's slope estimator

Sen (1968) developed a nonparametric procedure for estimating the slope of trend in a sample of n pairs of data. The Sen's method uses a linear model to estimate the slope of the trend, and the variance of the residuals should be constant in time calculated.

The slope estimates of N pairs of observations are computed based on the equation:

$$Q_k = \frac{P_j - P_i}{t_j - t_i} \text{ for } k = 1, \dots, N \quad \text{.... (7)}$$

Where, $P_j$ and $P_i$ are the observations at time j and i (j > i), respectively. The median of these N values of $Q_i$ is the Sen's estimator of slope, which is evaluated as follows:

$$Q_{\text{med}} = \begin{cases} Q_{[(N+1)/2]} & \text{if } N \text{ is odd} \\ \frac{Q_{[N/2]} + Q_{[(N+2)/2]}}{2} & \text{if } N \text{ is even} \end{cases}, \quad \text{.... (8)}$$

The $Q_{med}$ sign reveals the trend behavior, while its value indicates the magnitude of the trend.

## 2.5 Data Analysis and Interpretation

In this paper, the estimation of reference evapotranspiration ($ET_o$) by the Hargraves method was done using the Standardized Precipitation-Evapotranspiration Index (SPEI) package in R. The trend analysis was also done using the R programming language, and the ArcGIS software was used to generate maps. The inverse distance weighting (IDW) interpolation technique was used to map increases or decreases in monthly or seasonal $ET_o$.

## 3. RESULTS AND DISCUSSION

The results of the MK and SR tests for trend identification of monthly $ET_o$ were similar, and they are given in Table 2. The results reveal reveals significant patterns throughout the year. February consistently shows the strongest negative trends across all subdistricts, with strongest trend in Manvi ($Z_{MK}$ = -2.33, $p<0.05$) to Weakest trend in Sedam ($Z_{MK}$ = -1.72, $p>0.05$). Remaining months show both increasing and decreasing trends in $ET_o$, though not statistically significant. The results shows that in January, decreasing trends of $ET_o$ across all subdistricts, with $Z_{MK}$ values ranging from -0.98 (Gulbarga) to -1.56 (Manvi). The March and April months continue the decreasing trend pattern in $ET_o$, with $Z_{MK}$ values in March ranging from -1.49 (Sedam) to -1.92 (Manvi), and in April from -1.65 (Sedam) to -1.90 (Devadurga, Yadgir and Shahapur). In the month of May $ET_o$ trends across all subdistricts remain decreasing, with $Z_{MK}$ values between -1.43 (Raichur) and -1.63 (Manvi). However, June makes the shift in the $ET_o$ trends showing mostly increasing trends with $Z_{MK}$ range from -0.08 (Gulbarga, Raichur) to 0.55 (Afzalpur). The July month also shows the strongest increasing trends in $ET_o$ of the year, with $Z_{MK}$ values from 0.62 (Manvi) to 1.22 (Jewargi and Sedam). In August month, the mixed trends of $ET_o$ observed with slightly increasing values in some subdistricts and slightly decreasing $ET_o$ in others, with $Z_{MK}$ valus ranging from -0.28 (Yadgir, Shahapur) to 0.73 (Gulbarga). September months reverts to strong decreasing trends of $ET_o$, with $Z_{MK}$ values from -1.27 (Sedam) to -1.70 (Manvi). October and November months continue with decreasing trends in $ET_o$ but, magnitude is less. October month the $Z_{MK}$ values range from -0.35 (Manvi) to -1.07 (Afzalpur), while November month values from -0.24 (Devadurga and Sedam) to -0.39 (Afzalpur and Raichur). In December month, mixed trends of $ET_o$, with slight increasing values in some subdistricts ($Z_{MK}$ = 0.53 in Devadurga and Yadgir) and slight decreasing trend values or near-zero values in others ($Z_{MK}$ = -0.17 in Gulbarga, 0.03 in Afzalpur). February month significant decrease in ETo may be a sign of changing winter weather patterns in the region, perhaps as a result of the effects of global warming. The variations in the other months trends, especially the turn toward rising trends in the monsoon months (June–August), may be related to changes in crop cultivation practices, temperature changes, and variations in precipitation patterns (Maharana *et al.*, 2021). However, these data indicate that water demand patterns in this semi-arid region are changing throughout the year, they highlight the necessity of adaptive water management measures in agriculture (Gharib *et al.*, 2023). Rising air temperature emerged as the predominant driver of the observed upward trend in monthly $ET_o$, consistent with theoretical expectations. However, the anticipated positive association between wind speed and $ET_o$ was not observed. Instead, a statistically significant decrease in wind speed was found, partially offsetting the temperature-induced increase in $ET_o$. This unexpected finding highlights the need for further research to elucidate the underlying mechanisms and regional factors influencing wind $ET_o$ dynamics (Wang et al., 2020).

The MK, SR tests and Sens slope were also applied in order to study trends in the annual and seasonal $ET_0$ over the study period (1982–2022). Table 3 shows the MK, SR tests and Sens slope results for trend analysis. The study identified predominantly negative trends, especially pronounced during the summer months.In winter, most subdistricts show negative trends in $ET_o$ Manvi exhibiting the strongest decline ($Z_{MK}$ = -2.57, $p < 0.01$). Several other subdistricts, including Devadurga, Yadgir, Raichur, and Shahapur, also display significant negative trends ($p < 0.05$). The declining winter ETo trends across most subdistricts, particularly significant in Manvi, Devadurga, Yadgir, Raichur, and Shahapur, could be attributed to changes in temperature patterns, wind speeds, or land use practices. This trend may lead to reduced crop water requirements during winter, potentially benefiting water conservation efforts but necessitating adjustments in irrigation scheduling and crop selection strategies for local agriculture (Islam et al.,2022). All subdistricts demonstrated strong decreasing trends in summer $ET_o$, significant at the $p < 0.01$ level, Raichur exhibiting the strongest decline in $ET_o$ in the summer ($Z_{MK}$ = -2.89, $p < 0.01$). The monthly average $ET_o$ in mm/month shown in Fig. 2. This may be due to increasing summer temperatures in the region increase the evapotranspiration rate which affect the negatively impact crop yields and require farmers to adapt their cultivation practices, possibly shifting to more heat-tolerant varieties or adjusting planting dates to mitigate the effects of extreme summer conditions on agricultural productivity (Ishtiaq *et al.,* 2022).

Monsoon and post-monsoon seasons shows relatively weak, mostly negative trends, though not statistically significant ($Z_{MK} < 1.96$, P>0.05). However, Sedam is an exception, showing a slight positive trend during the monsoon season, not statistically significant. This indicate localized variations in monsoon and post-monsoon rainfall or humidity levels in that region, these results may still influence agricultural planning, particularly for rainfed crops and water harvesting strategies (Mandal *et al.,* 2020). Annually, all subdistricts exhibited negative trends, with Raichur showing the strongest decline (ZMK = -1.52, p>0.05) and Sedam the weakest (ZMK = -0.71, p>0.05).This annual trend may be due to complex interaction of climatic variables across the region. To adopt, farmers in this semi-arid area should think about selection of suitable crop, modify irrigation schedules and use of the water effectively. This can achieved by, adopting drought tolerant crop, precision irrigation systems plus practicing conservation agriculture so as water usage can be minimized to ensure productivity even when there are changes in weather patterns (Sharma *et al.,* 2022).

**Table 2: MK, SR tests results and Sen's slope estimated values for $ET_0$ trend in monthly time series**

| Subdistrict /Month | Test | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Afzalpur** | $Z_{MK}$ | -1.07 | -2.26[a] | -1.76 | -1.70 | -1.49 | 0.55 | 0.69 | 0.33 | -1.56 | -1.07 | -0.39 | 0.03 |
| | $Z_{SR}$ | -0.87 | -2.29[a] | -1.77 | -1.72 | -1.60 | 0.39 | 0.57 | 0.19 | -1.55 | -0.98 | -0.28 | 0.15 |
| | **S** | -0.12 | -0.23[a] | -0.26 | -0.19 | -0.32 | 0.05 | 0.07 | 0.02 | -0.26 | -0.17 | -0.08 | 0.01 |
| **Chitapur** | $Z_{MK}$ | -1.27 | -2.01[a] | -1.70 | -1.70 | -1.56 | 0.28 | 1.20 | 0.10 | -1.63 | -1.02 | -0.35 | 0.19 |
| | $Z_{SR}$ | -0.90 | -2.13[a] | -1.77 | -1.82 | -1.61 | 0.25 | 1.00 | -0.01 | -1.56 | -0.96 | -0.21 | 0.33 |
| | **S** | -0.13 | -0.25[a] | -0.23 | -0.20 | -0.32 | 0.03 | 0.18 | 0.02 | -0.26 | -0.18 | -0.06 | 0.04 |
| **Devadurga** | $Z_{MK}$ | -1.22 | -2.19[a] | -1.83 | -1.90 | -1.52 | 0.28 | 0.86 | -0.24 | -1.63 | -0.66 | -0.24 | 0.53 |
| | $Z_{SR}$ | -0.98 | -2.21[a] | -1.88 | -1.99 | -1.62 | 0.37 | 0.74 | -0.17 | -1.54 | -0.65 | -0.13 | 0.56 |
| | **S** | -0.12 | -0.25[a] | -0.22 | -0.21 | -0.31 | 0.05 | 0.11 | -0.02 | -0.32 | -0.13 | -0.05 | 0.07 |
| **Gulbarga** | $Z_{MK}$ | -0.98 | -2.06[a] | -1.58 | -1.67 | -1.56 | -0.08 | 1.07 | 0.73 | -1.67 | -0.84 | -0.28 | -0.17 |
| | $Z_{SR}$ | -0.75 | -2.16[a] | -1.72 | -1.73 | -1.59 | -0.13 | 0.82 | 0.50 | -1.58 | -0.86 | -0.18 | 0.08 |
| | **S** | -0.13 | -0.22[a] | -0.23 | -0.19 | -0.30 | 0.00 | 0.17 | 0.12 | -0.24 | -0.16 | -0.05 | -0.02 |
| **Yadgir** | $Z_{MK}$ | -1.22 | -2.17[a] | -1.81 | -1.90 | -1.52 | 0.28 | 0.86 | -0.28 | -1.63 | -0.66 | -0.26 | 0.53 |
| | $Z_{SR}$ | -0.98 | -2.18[a] | -1.86 | -1.99 | -1.59 | 0.37 | 0.74 | -0.17 | -1.54 | -0.65 | -0.13 | 0.56 |
| | **S** | -0.12 | -0.25[a] | -0.22 | -0.21 | -0.31 | 0.05 | 0.12 | -0.02 | -0.33 | -0.13 | -0.05 | 0.06 |
| **Jewargi** | $Z_{MK}$ | -1.29 | -2.01[a] | -1.67 | -1.72 | -1.56 | 0.28 | 1.22 | 0.10 | -1.63 | -1.02 | -0.35 | 0.19 |
| | $Z_{SR}$ | -0.91 | -2.13[a] | -1.76 | -1.83 | -1.61 | 0.25 | 1.00 | -0.01 | -1.56 | -0.96 | -0.21 | 0.33 |
| | **S** | -0.13 | -0.25[a] | -0.23 | -0.19 | -0.32 | 0.03 | 0.18 | 0.02 | -0.26 | -0.18 | -0.06 | 0.04 |
| **Manvi** | $Z_{MK}$ | -1.56 | -2.33[a] | -1.92 | -1.83 | -1.63 | 0.44 | 0.62 | -0.21 | -1.70 | -0.35 | -0.33 | 0.30 |
| | $Z_{SR}$ | -1.30 | -2.26 | -1.97 | -1.95 | -1.61 | 0.47 | 0.52 | -0.23 | -1.79 | -0.48 | -0.19 | 0.32 |
| | **S** | -0.14 | -0.26[a] | -0.20 | -0.21 | -0.34 | 0.04 | 0.05 | -0.02 | -0.39 | -0.06 | -0.05 | 0.03 |
| **Raichur** | $Z_{MK}$ | -1.52 | -1.98 | -1.70 | -1.85 | -1.43 | -0.08 | 0.80 | 0.06 | -1.43 | -0.62 | -0.39 | 0.48 |
| | $Z_{SR}$ | -1.30 | -1.94 | -1.65 | -1.98 | -1.51 | -0.01 | 0.69 | -0.01 | -1.42 | -0.67 | -0.16 | 0.51 |
| | **S** | -0.15 | -0.23 | -0.21 | -0.18 | -0.31 | -0.01 | 0.11 | 0.01 | -0.27 | -0.14 | -0.10 | 0.05 |
| **Sedam** | $Z_{MK}$ | -1.18 | -1.72 | -1.49 | -1.65 | -1.61 | 0.35 | 1.22 | 0.51 | -1.27 | -0.86 | -0.24 | 0.08 |
| | $Z_{SR}$ | -0.94 | -1.81 | -1.39 | -1.71 | -1.54 | 0.42 | 1.06 | 0.55 | -1.32 | -0.85 | -0.19 | 0.25 |
| | **S** | -0.13 | -0.20 | -0.18 | -0.16 | -0.34 | 0.05 | 0.18 | 0.06 | -0.21 | -0.17 | -0.05 | 0.01 |
| **Shahapur** | $Z_{MK}$ | -1.20 | -2.15[a] | -1.81 | -1.90 | -1.52 | 0.28 | 0.86 | -0.28 | -1.63 | -0.66 | -0.26 | 0.53 |
| | $Z_{SR}$ | -0.96 | -2.18[a] | -1.86 | -1.99 | -1.59 | 0.37 | 0.74 | -0.17 | -1.54 | -0.65 | -0.13 | 0.56 |
| | **S** | -0.12 | -0.25[a] | -0.22 | -0.21 | -0.31 | 0.05 | 0.11 | -0.02 | -0.33 | -0.13 | -0.05 | 0.06 |

a - 5% level significance, b - 1% level significance

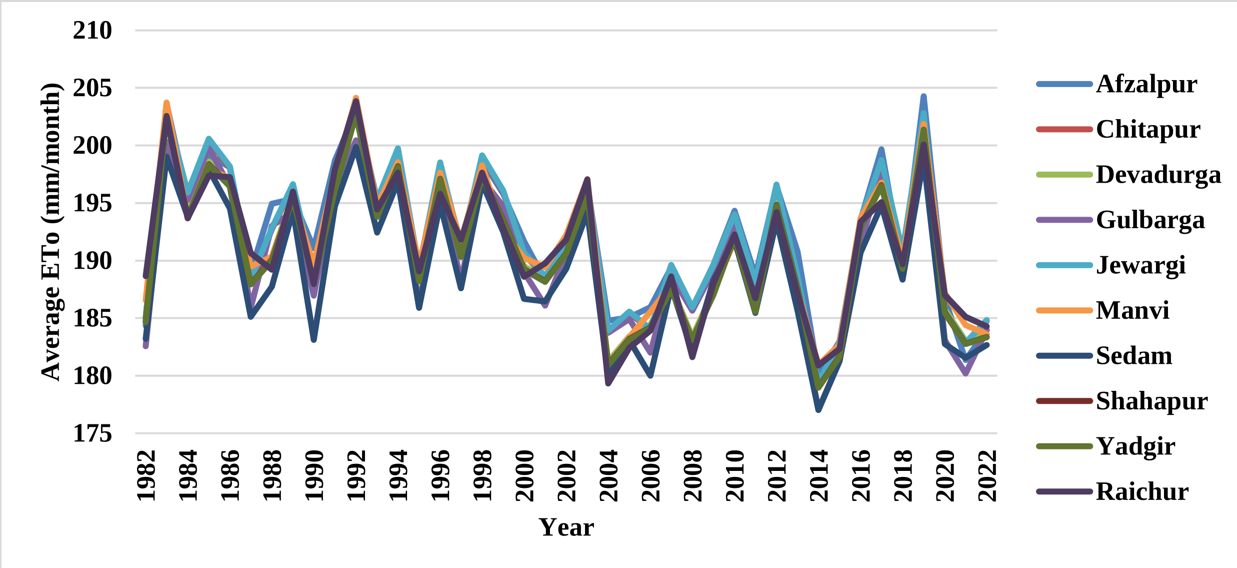


**Fig. 2: Variations of summer season $ET_0$ in all subdistricts during the study period**

Sen's slope estimations are spatially interpolated using ArcGIS's Inverse Distance Weighting (IDW) approach, which reveals $ET_o$ pattern distribution trends across northeastern dry zone of Karnataka (Fig. 3). The slopes show an average decreasing trend in $ET_o$ during the winter, ranging from -0.18 mm/month (Manvi) to -0.15 mm/month (Chitapur, Jewargi and Gulbarga). In summer season, strongest declining trends in $ET_o$ with slope average value -0.246 mm/month across all subdistricts, highlighting a significant reduction in $ET_o$ during this period. The post-monsoon and monsoon seasons shows comparatively weaker trends of $ET_o$, with slopes ranging from -0.05 mm/month to 0.01 mm/month and -0.05 mm/month to 0.03 mm/month respectively. The annual slopes indicate an overall decreasing trend in ETo across the region, varying from -0.12 (Manvi) to -0.04 (Sedam), with most subdistricts showing moderate decreasing trend in ETo. The variation of $ET_o$ in the spatial scale across the study area particularly, and relatively higher in Manvi may be attributed to the differences in the physical features such as land surface characteristics, soil type and cultivation practices (Ademe *et al.*, 2020).

**Table 3: MK, SR tests results and Sen's slope estimated values for $ET_0$ trend in seasonal and annual time**

| Subdistrict /Month | Test | Winter | Summer | Monsoon | Post-monsoon | Annual |
|---|---|---|---|---|---|---|
| **Afzalpur** | $Z_{MK}$ | -1.67 | -2.66[b] | -0.21 | -0.21 | -1.20 |
| | $Z_{SR}$ | -1.77 | -2.69[b] | -0.35 | -0.24 | -1.30 |
| | S | -0.16 | -0.25[b] | -0.01 | -0.03 | -0.07 |
| **Chitapur** | $Z_{MK}$ | -1.70 | -2.71[b] | -0.21 | -0.17 | -1.00 |
| | $Z_{SR}$ | -1.66 | -2.81[b] | -0.23 | -0.04 | -1.06 |
| | S | -0.15 | -0.25[b] | -0.02 | -0.03 | -0.06 |
| **Devadurga** | $Z_{MK}$ | -2.15[a] | -2.73[b] | -0.28 | 0.01 | -1.04 |
| | $Z_{SR}$ | -2.17[a] | -2.94[b] | -0.33 | 0.11 | -1.10 |
| | S | -0.16[a] | -0.25[b] | -0.03 | 0.01 | -0.07 |
| **Gulbarga** | $Z_{MK}$ | -1.65 | -2.48[b] | -0.06 | -0.24 | -0.78 |
| | $Z_{SR}$ | -1.61 | -2.49[b] | -0.05 | -0.24 | -0.79 |
| | S | -0.15 | -0.25[b] | 0.00 | -0.04 | -0.07 |
| **Yadgir** | $Z_{MK}$ | -2.17[a] | -2.73[b] | -0.28 | 0.01 | -1.04 |
| | $Z_{SR}$ | -2.17[a] | -2.94[b] | -0.33 | 0.11 | -1.10 |
| | S | -0.16[a] | -0.25[b] | -0.03 | 0.01 | -0.08 |
| **Jewargi** | $Z_{MK}$ | -1.70 | -2.71[b] | -0.21 | -0.17 | -1.00 |
| | $Z_{SR}$ | -1.66 | -2.81[b] | -0.23 | -0.04 | -1.06 |
| | S | -0.15 | -0.25[b] | -0.02 | -0.03 | -0.06 |
| **Manvi** | $Z_{MK}$ | -2.57[b] | -2.82[b] | -0.51 | 0.06 | -1.49 |
| | $Z_{SR}$ | -2.57[b] | -3.04[b] | -0.58 | 0.03 | -1.48 |
| | S | -0.18[b] | -0.25[b] | -0.05 | 0.01 | -0.12 |
| **Raichur** | $Z_{MK}$ | -2.26[a] | -2.89[b] | -0.57 | -0.03 | -1.52 |
| | $Z_{SR}$ | -2.24[a] | -3.23[b] | -0.59 | 0.08 | -1.57 |
| | S | -0.16[a] | -0.24[b] | -0.05 | -0.01 | -0.11 |
| **Sedam** | $Z_{MK}$ | -1.67 | -2.39[b] | 0.30 | -0.39 | -0.71 |
| | $Z_{SR}$ | -1.56 | -2.59[b] | 0.23 | -0.23 | -0.80 |
| | S | -0.16 | -0.22[b] | 0.03 | -0.05 | -0.04 |
| **Shahapur** | $Z_{MK}$ | -2.17[a] | -2.73[b] | -0.28 | 0.01 | -1.04 |
| | $Z_{SR}$ | -2.17[a] | -2.94[b] | -0.33 | 0.11 | -1.10 |
| | S | -0.16[a] | -0.25[b] | -0.03 | 0.01 | -0.08 |

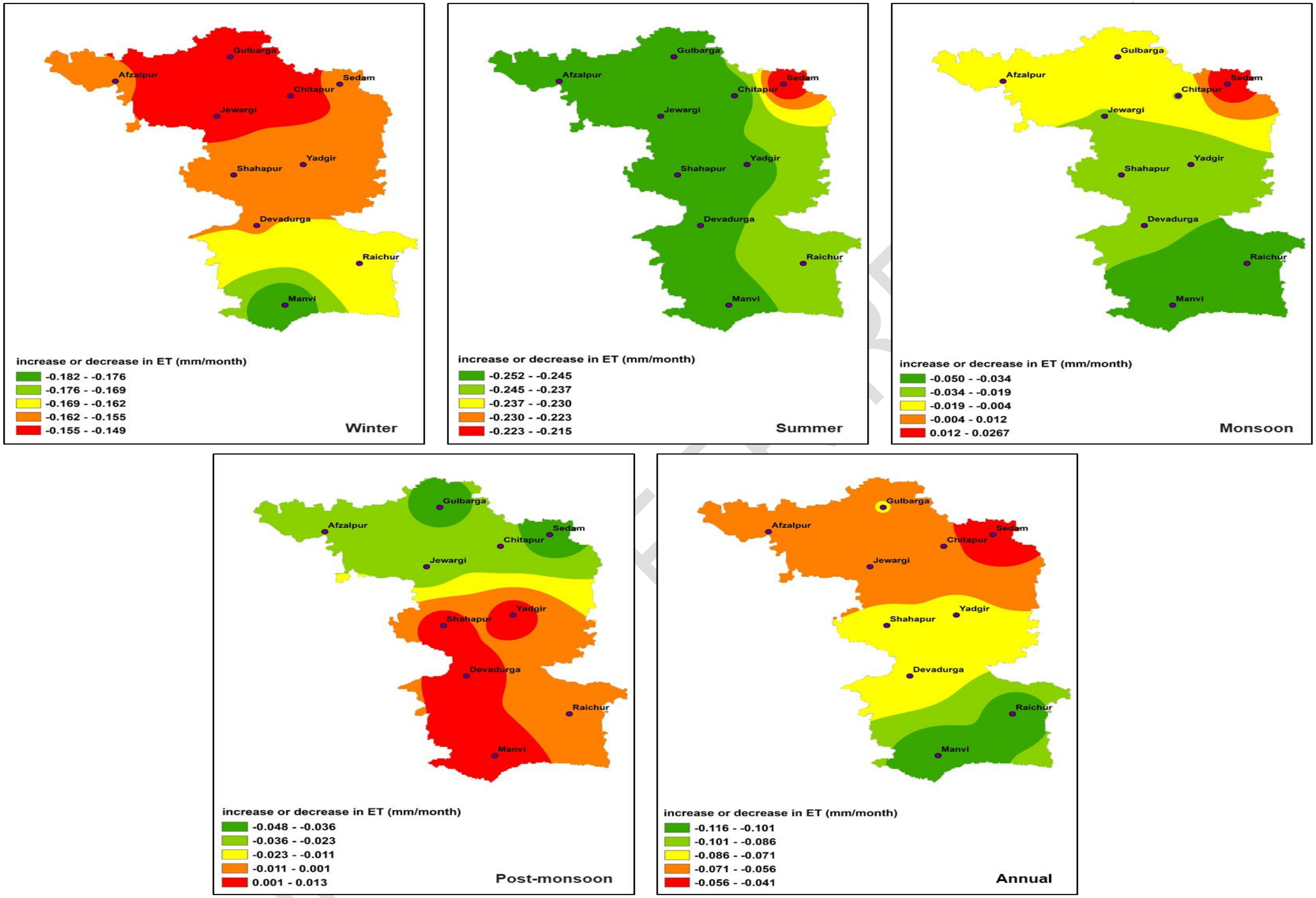


**Fig. 3: Rate of change of $ET_0$ seasonally and annually interpolated using the inverse distance weighting (IDW) method in ArcGIS software.**

## 4. CONCLUSION

The study was aimed to analyze the spatiotemporal trends of ETo data for 10 main sub districts in the North Eastern Dry Zone of Karnataka, India, from 1982-2022. The result of the analysis reveal that there is a combined trend of $ET_o$ different seasons in all subdistricts. Thus, the analysis indicated the increase and decrease in monthly, seasonal, and annual $ET_o$. February remained the most negative month in all subdistricts ($Z_{MK}$ -2.33 in Manvi and -1.72 in Sedam, $p<0.05$). Largest number of significant trends were identified in the summer and winter series with Manvi subdistrict having strongest decreasing winter trend ($Z_{MK} = -2.57$, $p<0.01$) and Raichur having strongest decreasing $ET_o$ summer trend ($Z_{MK} = -2.89$, $p<0.01$). Sen's slope estimates revealed the average decrease of -0.18 to -0.15 mm per month in winter and an average value of -0.246 mm/month $ET_o$ in summer. The monsoon and post-monsoon trends were relatively weaker (- 0.05 to 0.03 mm/month) and mostly insignificant. The annual trends shows slightly declining trends (-0.12 to -0.04 mm/month). The ArcGIS's IDW technique was used to identify variations in $ET_o$ change at the regional level. Most of these trends were found to be significant; however, rising air temperature was the most important factor that contributed to the observed increasing trends in some months, while a decrease in wind speeds partly negated the effect. The present study may have some implications regarding water supply and farming in the area of interest. More studies on the regional aspects and mechanisms controlling the wind-ETo relations and variability and effective water management intervention measures are required to address the emerging trends.

## Disclaimer (Artificial intelligence)

**Option 1:**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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