

Original Research Article

Investigating Spatiotemporal Variation of Evaporation ~~Evapo-transpiration~~ Trends using Non-Parametric Statistical Techniques across North Eastern Dry Zone of Karnataka, India

Commented [U1]: In general, this paper seems like short communication rather than a manuscript. However, if it is enriched and rewritten well again still it is definitely important topic. Therefore, the revision have to be addressed the comments shown in each sections for publication.

ABSTRACT

Commented [U2]: It is okay, but include the comments below.

This study analyzes trends in reference evapotranspiration (ET_0) across 10 subdistricts in the North Eastern Dry Zone (NEDZ) of Karnataka, India, using non-parametric statistical techniques. Data from 1982-2022 reveals complex spatiotemporal patterns in ET_0 variability. Monthly analysis shows ~~that there were~~ both ~~an~~ increasing and decreasing trends. Winter and summer exhibit statistically significant decreasing trends in most subdistricts, with potential implications for water availability and agricultural practices. Monsoon and post-monsoon trends are more varied. Notably, rising air temperature drives the observed upward trends, but a surprising decrease in wind speed partially offsets this effect. Seasonal and annual analyses display similar findings. Winter and summer trends are significant across all subdistricts, highlighting decreasing ET_0 levels. Annual trends, though not statistically significant at subdistricts level, indicate a slight overall decrease. Our results contribute to an in-depth understanding of ~~ET_0 - ET_0~~ dynamics in NEDZ. More research is necessary to clarify the reasons for the unexpected decrease in wind speed and to create customized water management plans that address these shifting patterns.

Commented [U3]: Please say "o", you are typing "0" in the entire section of the manuscript.

Commented [U4]: The magnitude of change of ET_0 per month or season should be indicated here as it is one of your objectives. Where is the third objective result, the spatial patterns of ET_0 ?

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

1. INTRODUCTION

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. 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).

Commented [U5]: Good and well organized. But, it needs more justification why to conduct ET_0 trends over the regions? What is the problems in the region, in reference to the agriculture? What others works on the region and what is the new knowledge gained by your study?

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). Parametric trend tests are more powerful than non-parametric ones, but they require data to be independent and normally distributed. 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 (Novotny and Stefan, 2007; Yaning *et al.*, 2009).

Commented [U6]: Sure??? I think non-parametric trend tests are more powerful than parametric, on contrary.

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 Hargreaves method is a simple and widely used method for 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.

Commented [U7]: Is that? Why not penman monteith method? Penman monteith method is the solely recommended and widely used E_t determination method. Here you are using ERA5-AG data set; you can use NASA dataset instead to access all metrological data for the use of penman monteith method.

The aim of this study was to investigate the spatiotemporal trends on ET_0 time series over Northeastern Dry Zone of Karnataka, India. i) to analyze the temporal trend in monthly, seasonal and annual evaporation (ET_0) 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_0) and (iii) to analyze the spatial pattern of trends and its magnitude in monthly, seasonal, and annual evaporation (ET_0) using The inverse distance weighting (IDW) in ArcGIS software.

2. MATERIAL AND METHODS

Commented [U8]: This section is enough described for MM.

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 $76^{\circ} 10' E$ to $77^{\circ} 30' E$ and $16^{\circ} 0' N$ to $17^{\circ} 30' N$ and falls in Yadgir, Raichur, and Gulbarga districts and 10 subdistricts of Karnataka (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 $31^{\circ}C$ to $42^{\circ}C$; during the monsoon, from $28^{\circ}C$ to $32^{\circ}C$; and in the winter, from $15^{\circ}C$ to $26^{\circ}C$. 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 (KRSAC). The ERA5-AG daily maximum and minimum temperature dataset with a native horizontal resolution of about 9.6 km (released on a regular $0.1^{\circ} \times 0.1^{\circ}$ 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.

Commented [U9]: No any observed data in the region, and if not it is ok. Why ERA5_AG datasets? You have to justify it well?

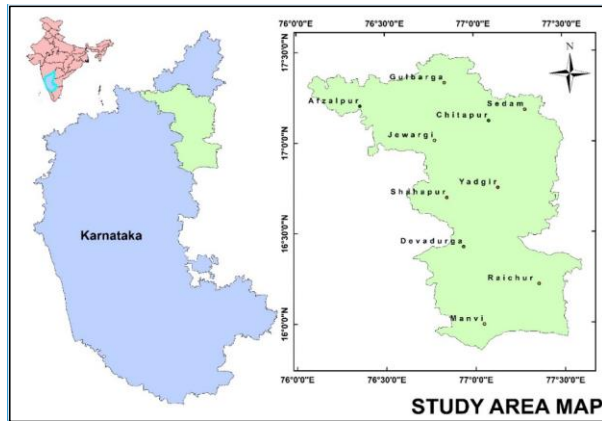


Fig. 1. Study area map with selected subdistricts

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

No	Subdistrict Name	Geographical characteristics		
		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 Hargreaves 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

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

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

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).

Commented [U10]: This map is unreadable. It must be well prepared again.

Commented [U11]: All they are too old citations

Commented [U12]: Also too old?

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 based on the correlation between the ranks and sequences of a time series. For a given time series $\{X_i, i = 1, 2, \dots, n\}$, the null hypothesis H_0 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:

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

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

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

$$\text{Var}(S) = \left[n(n-1)(2n+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5) \right] / 18,$$

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;

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

By applying a two-tailed test, for a specified significance level α , the significance of the trend can be evaluated. In particular, in this work, the rainfall and runoff series have been examined for three different significance levels (SL) equal to 90%, 95%, and 99% (Achite *et al.*, 2022).

Commented [U13]: What is the importance of this statement, your objectives are all about the spatio temporal trends of Eto.

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 R_{sp} and standardized statistics Z_{sp} are defined as

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

$$Z_{sp} = R_{sp} \sqrt{\frac{n-2}{1 - R_{sp}^2}}$$

In these equations, D_i is the rank of i^{th} observation, I is the chronological order number, n is the total length of the time series data, and Z_{sp} is Student's t -distribution with $(n-2)$ degree of freedom. The positive values of Z_{sp} 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 $t_{(n-2, 1-\alpha/2)}$. If $|Z_{sp}| > t_{(n-2, 1-\alpha/2)}$, (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:

$$Q_k = \frac{P_j - P_i}{t_j - t_i} \text{ for } k = 1, \dots, N$$

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_k is the Sen's estimator of slope, which is evaluated as follows:

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

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_{0g}) 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_{0g} .

3. RESULTS AND DISCUSSION

3.1 Monthly Analysis

The results of the MK and SR tests for trend identification of monthly ET_{0g} were similar, and they are given in Table 2. As shown, the ET_{0g} had a combination of both increasing and decreasing trends in the monthly analysis. The trend tests revealed February month shows statistically significant trends in the subdistricts expect at Raichur and Sedam (Fig. 2). In January, February, March, April, May, September, October and November all subdistricts shows decreasing trend in the monthly ET_{0g} . However, Raichur shows no trend of ET_{0g} in the month of November. The June, July and December months in most of the subdistricts shows increasing trend in the monthly ET_{0g} . Although, in June and December few subdistricts (Afzalpur, Gulbarga and Sedam) shows no trend. In August, Gulbarga and Sedam subdistricts has shown negative ET_{0g} trends remaining all subdistricts shows no trend of ET_{0g} .

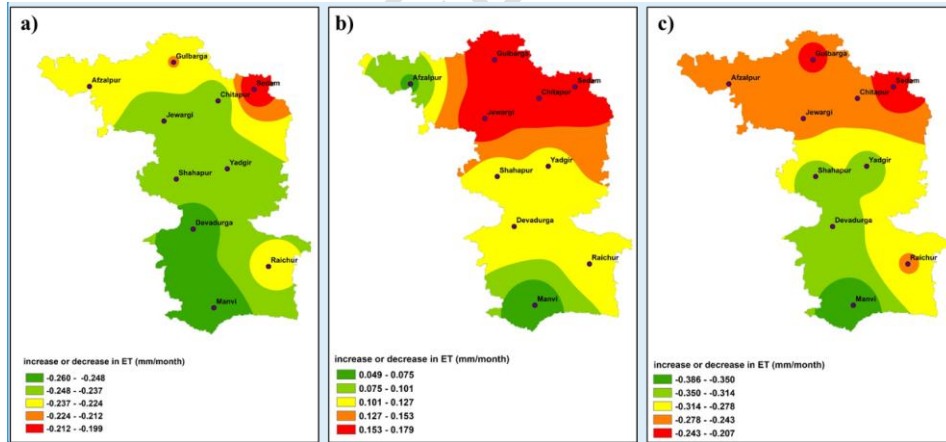


Fig. 2: Rate of change of ET_0 in different Months interpolated using the inverse distance weighting (IDW) method in ArcGIS software (a- February, b- July and c- September).

The maximum values of increasing rate (0.18 mm/month) and decreasing rate (-0.39 mm/month) slopes of the trends in the monthly ET_0 data were observed in Chitapur, Jewargi and Sedam (July) and in Manvi (September), respectively. The trends of the monthly ET_0 for the above-mentioned months are presented in Fig. 2. Rising air temperature emerged as the predominant driver of the observed upward trend in

Commented [U14]: This section seems shallow, therefore the authors try to improve it well by supporting by others works before the endorsement for publication.

Commented [U15]: Check this month, here increasing and you are saying that decreasing in all subdistricts in next sentence. So, check it.

Commented [U16]: Use consistent terms, say that decreasing ET_0 trends

Commented [U17]: What about others months?

Commented [U18]: 1st make the maps to be more readable; the text, north arrow, scale...
2nd, here you are conducted simple IDW interpolation over the region. But, you have to conduct geo statistical analysis to make your result more clearer and readable.

monthly ET_0 , consistent with theoretical expectations. However, the anticipated positive association between wind speed and ET_0 was not observed (Liuzzo *et al.*, 2016). Instead, a statistically significant decrease in wind speed was found, partially offsetting the temperature-induced increase in ET_0 . This unexpected finding highlights the need for further research to elucidate the underlying mechanisms and regional factors influencing wind ET_0 dynamics (Wang *et al.*, 2020).

3.2 Annual and Seasonal Analysis

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 significance, which were similar for both tests in tested time series. Among the different season's trend tests, winter and summer shows statistically significant trends of ET_0 shown in Fig. 3. The ET_0 in winter is significant in Devadurga, Yadgir, Manvi, Raichur and Shahapur subdistricts whereas, the ET_0 trend in summer was significant at all subdistricts. In the winter and summer, shows decreasing trend in the ET_0 at all subdistricts. However, the monsoon and post-monsoon shows no trend at all subdistricts. The trend tests revealed no statistically significant trends at annually at all subdistricts but, results revealed that there is decrease trend of ET_0 annually.

Commented [U19]: The results are so good but, not linked with climate smart agricultural technologies or the problem that faced in the area. Answers on so what, what will be the solution for the climate variability increase in ET_0 and erratic rainfall distribution i.e., climate adaptation strategies are expected for each districts.

UNDER PEER REVIEW

Table 2: MK, SR tests results and Sen's slope estimated values for ET₀ 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

The maximum values of decreasing rate (0.25 mm/month) slopes of the significant trends in the seasonal ET_0 data were observed in all subdistricts (in summer) except Sedam. The maximum annual decrease rate of ET_0 slope of trend was observed in case of Manvi subdistrict (0.12 mm/year). The trends of the seasonal and annual ET_0 for the above-mentioned stations are presented in Fig. 4. Most subdistricts exhibit significant decreasing trends in evapotranspiration (ET_0) during winter, suggesting potential implications for water availability and agricultural practices in the colder months. All subdistricts show statistically significant decreasing trends in ET_0 during summer, which could have consequences for crop

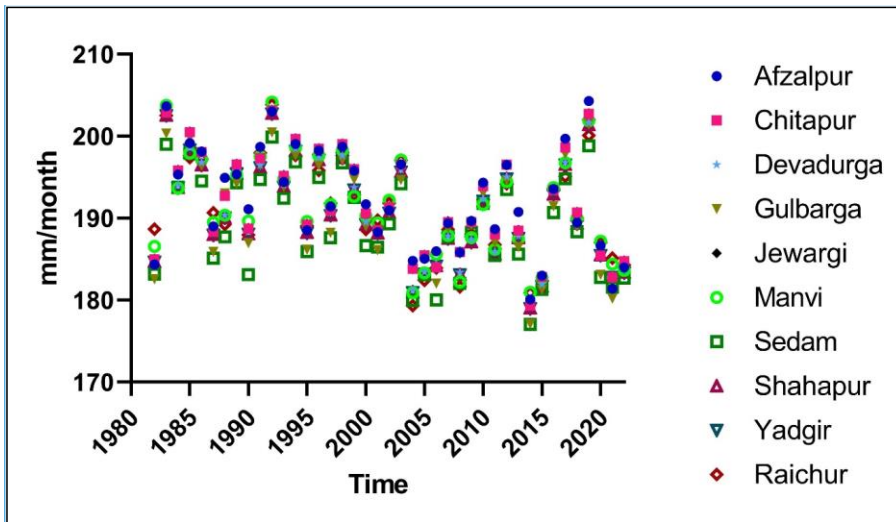


Fig. 3: Variations of summer season ET_0 in all subdistricts during the study period

growth and water resource management during this crucial period. ET_0 trends vary across subdistricts in the monsoon and post-monsoon seasons, indicating a more complex interplay of factors influencing ET_0 during these periods. While some subdistricts show significant annual decreasing trends in ET_0 , others do not exhibit statistically significant changes. This highlights the importance of considering seasonal variations when assessing overall ET_0 trends (Bhave *et al.*, 2018).

Commented [U20]: It is unreadable. It is better if you use line graphs

Table 3: MK, SR tests results and Sen's slope estimated values for ET₀ 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

Commented [U21]: This is the most important section of your findings. However, you have made shallow discussion on the changes of ET₀ on these seasons. To which season crop production is conducted, what is the changes on ET₀? And what is the adaptation measures to increase the availability of water against the increased ET₀?

UNDER REVIEW

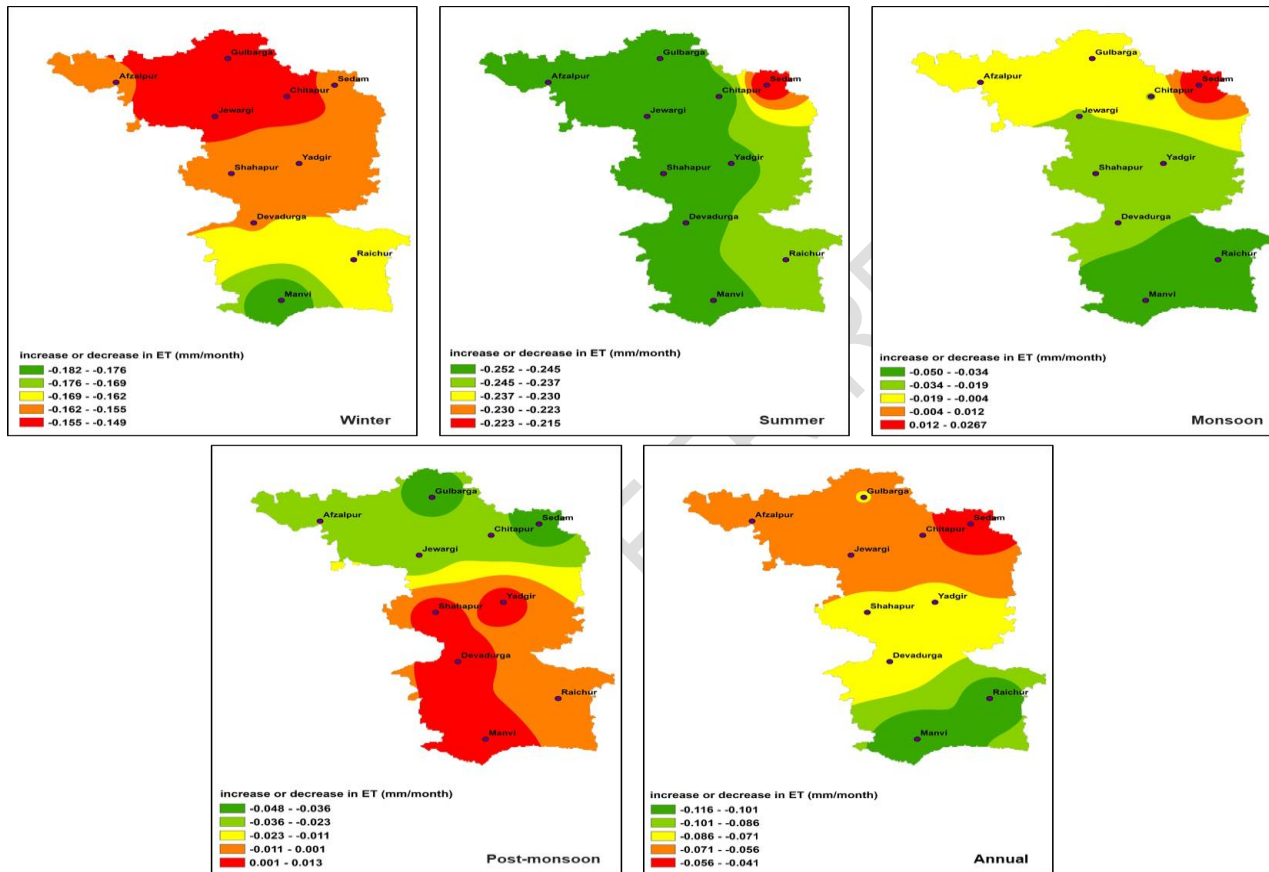


Fig. 4: Rate of change of ET₀ seasonally and annually interpolated using the inverse distance weighting (IDW) method in ArcGIS software.

4. CONCLUSION

In this study, spatiotemporal trends in ET_0 data for 10 main subdistricts in NEDZ of Karnataka were analyzed. The analysis revealed a complex picture of ET_0 trends across subdistricts and seasons. The results showed that increasing and decreasing trends were found for monthly, seasonal and annual ET_0 . The annual trends all subdistricts were significant at the 5% and 1% significant level. The highest numbers of significant trends were found in the summer and winter series, respectively, with potential implications for water availability and agricultural practices, monsoon and post-monsoon trends were more varied. Notably, rising air temperature was the dominant driver of the observed increasing trends, but a surprising decrease in wind speed partially offset this effect. Further research is needed to elucidate the underlying mechanisms and regional factors influencing wind- ET_0 dynamics and develop tailored water management strategies to address these changing trends.

REFERENCES

- Achite, M., Caloiero, T. and Toubal, A. K., 2022. Rainfall and runoff trend analysis in the Wadi Mina Basin (Northern Algeria) using non-parametric tests and the ITA method. *Sustainability*, 14(16), p.9892.
- Bhave, A.G., Conway, D., Dessai, S. and Stainforth, D.A., 2018. Water resource planning under future climate and socioeconomic uncertainty in the Cauvery River Basin in Karnataka, India. *Water resources research*, 54(2), pp.708-728.
- Chen SB, Liu YF, Thomas A (2006) Climatic change on the Tibetan plateau: potential evapotranspiration trends from 1961–2000. *Climatic Change* 76:291–319
- Hargreaves G.H., 1994. Defining and using reference evapotranspiration. *Journal of Irrigation and Drainage Engineering* 120: 1132–1139.
- IPCC (2007) Summary for policymakers in climate change 2007: the physical science basis. Contrib Work Gr I to Fourth Assess Rep Intergov Panel Clim Chang Cambridge Univ Press UK
- Kendall M. G (1975) Rank correlation methods. Griffin, London
- Lehmann, E.L., 1975. Statistical methods based on ranks. *Nonparametrics. San Francisco, CA, Holden-Day.*
- Liu Q, Yang Z, Cui B, 2008. Spatial and temporal variability of annual precipitation during 1961–2006 in Yellow River Basin, China. *J Hydrol* 361:330–338
- Liuzzo, L., Viola, F. and Noto, L.V., 2016. Wind speed and temperature trends impacts on reference evapotranspiration in Southern Italy. *Theoretical and applied climatology*, 123, pp.43-62.
- Machiwal D, Gupta A, Jha MK, Kamble T (2019) Analysis of trend in temperature and rainfall time series of an Indian arid region: comparative evaluation of salient techniques. *Theor Appl Climatol* 136: 301–320.
- Mann H. B (1945) Nonparametric tests against trend. *Econometrica* 13:245–259
- Nautiyal, S., Bhaskar, K. and Khan, Y. D., 2018. Biodiversity conservation in semi-arid landscape: Central and North Eastern Dry Zones of Karnataka.
- Novotny EV, Stefan HG (2007) Stream flow in Minnesota: indicator of climate change. *J Hydrol* 334:319–333.
- Sen, P.K., 1968, Estimates of the regression coefficient based on Kendall's tau. *J. Am. Stat. Assoc.*, 63, 1379–1389.
- Thiel H (1950) A rank-invariant method of linear and polynomial regression analysis, Part 3. *Proceedings of Koninklijke Nederlandse Akademie van Wetenschappen A* 53:1397–1412
- Wang, K., Xu, Q. and Li, T., 2020. Does recent climate warming drive spatiotemporal shifts in functioning of high-elevation hydrological systems? *Science of the Total Environment*, 719, p.137507.
- Yaning C, Changchun X, Xingming H, Weihong L, Yapeng C, Chenggang Z, Zhaoxia Y (2009) Fifty-year climate change and its effect on annual runoff in the Tarim River Basin, China. *Quatern Int* 208:53–61
- Yue, S., Pilon, P. and Cavadias, G., 2002. Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of hydrology*, 259(1-4), pp.254-271.

Commented [U22]: To which sub districts the change in ET_0 were more pronounced and recommended adaptation strategies should be suggested here.

Commented [U23]: Your conclusion and recommendation must be supported with the figure or data, how much the change in ET_0 for summer/or winter?

Commented [U24]: Have you conducted the trend analysis for wind speed? So, how could you know whether it has an effect and why others factors not?

Commented [U25]: Rather better to say rainfall- ET_0 dynamics and the water management options.

Commented [U26]: Too small references for this manuscript. You should enrich your work by supporting others work, what others say and what you get? What is the new knowledge you gained over others? And so on....