PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.5119

HORIZON
e-Publishing Group

RESEARCH ARTICLE

Long-term analysis of reference evapotranspiration variations in the lower Bhavani basin

Pavithran P[1], Pazhanivelan S[2*], Sivamurugan A P[2], Ragunath K P[2], Selvakumar S[2], Vanitha K[3], Sakthivel S[1] & Shanmugapriya P[2]

[1]Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore - 641003, India

[2]Centre for Water and Geospatial Studies, Tamil Nadu Agricultural University, Coimbatore - 641003, India

[3]Department of Fruit Science, Tamil Nadu Agricultural University, Coimbatore - 641003, India

*Email: pazhanivelans@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 18 September 2024
Accepted: 12 October 2024
Available online
Version 1.0 : 31 October 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Pavithran P, Pazhanivelan S, Sivamurugan AP, Ragunath KP, Selvakumar S, Vanitha K, Sakthivel S, Shanmugapriya P. Long-term analysis of reference evapotranspiration variations in the lower Bhavani basin. Plant Science Today (Early Access). https://doi.org/10.14719/pst.5119

Abstract

Evapotranspiration is a crucial component of the hydrological cycle and is profoundly influenced by climate change. Assessing regional evapotranspiration changes is essential for effective water resource management. The study investigated the dynamics of reference evapotranspiration in the Lower Bhavani Basin, a region with diverse landscapes increasingly vulnerable to climatic variability. Reference evapotranspiration data from the Food and Agriculture Organization using the AgERA5 dataset was analyzed to assess annual and seasonal trends from 2000 to 2022. The result showed that the mean yearly reference evapotranspiration in the basin is 1672.87 mm, with a significant decline of 3.53 mm per year. Seasonal analysis revealed a consistent decreasing trend across all seasons, with the southwest monsoon season showing the most significant reduction in evapotranspiration rates. The notable shift in the annual evapotranspiration rate was observed in 2016, highlighting the impact of climate change. Further, temperature, solar radiation and relative humidity were identified as the dominant factors influencing evapotranspiration rates in the basin. The relative moisture index indicated prevalent dry conditions, making the region susceptible to water stress. The findings provide critical insights for regional water resources management and accentuate the need for sustainable water management strategies to mitigate the impacts of climate change.

Keywords

basin; climate change; evapotranspiration; Penman-Monteith method; trend analysis

Introduction

Global warming is primarily caused by the rapid increase in greenhouse gas emissions, leading to exacerbated changes in global climatic patterns. The average Earth's temperature has increased by approximately 1.5 ˚C over pre-industrial levels, with projections indicating a potential increase of up to 3.2˚C by 2100 (1). The rise in the Earth's temperature poses profound implications for food production, the global water cycle and the integrity of natural ecosystem services (2). However, climate change exerts a significant influence on the global hydrological cycle by altering precipitation patterns, intensifying extreme weather events such as floods and droughts and increasing evapotranspiration rates due to rising temperatures. Evapotranspiration is a crucial component of the hydrological cycle, contributing about 60-65 per cent of global precipitation and substantially influenced by climate change worldwide (3, 4). It is a complex process influenced by various factors and is extensively affected by climate variability (5). Evapotranspiration is a crucial metric for studying the impacts of climate change at the regional scale, as it significantly influences surface run-off, water storage and water availability.

The atmospheric evaporative demand is a critical parameter regulating water movement in the land-atmosphere continuum (6). It is generally unevenly distributed and primarily governed by climatic and ecological factors. The evaporation from the Earth's surface increases with global temperature, further intensifying the water cycle's dynamics. The evaporative demand is closely correlated with solar radiation and water availability, which helps understand climate change's impact on water resources (7). Estimating evapotranspiration is challenging due to the complexity of the process in the natural ecosystems. Reference evapotranspiration (ET_0) represents the evapotranspiration from the reference surface (grass) under prevailing meteorological conditions without limitations on water availability (8). It provides the evaporation potential of the atmosphere. It is the basis for assessing the evapotranspiration and water balance for various applications, including irrigation scheduling, water resources planning and climatological studies (9, 10). Moreover, evapotranspiration is the crucial variable employed in drought assessment studies, providing insights into drought severity.

Numerous empirical methods have been developed to estimate the reference evapotranspiration; however, the accuracy depends on the input weather variables (11). Blaney-Criddle, pan evaporation, radiation, Penman-Monteith, *etc.,* are commonly employed to estimate the reference evapotranspiration. In addition, a combination approach (energy and mass transfer) is also used to obtain the reference evapotranspiration. The Penman-Monteith method, outlined in the FAO irrigation and drainage paper No. 56, is the standardized approach for calculating reference evapotranspiration (8). It provides reliable estimates of reference evapotranspiration based on meteorological variables across diverse locations and climatic conditions (12).

The spatiotemporal distribution of evapotranspiration is dynamic, driven by the intricate interplay of various climatic and environmental factors. Air temperature and vapour pressure deficit significantly influence reference evapotranspiration, while vegetation activity is crucial in determining the magnitude of actual evapotranspiration (13, 14). Evapotranspiration trends are distributed unevenly, and both increasing and decreasing trends have been noticed across different regions, indicating the complexity of the evapotranspiration process (10, 15-17). The evaporative demand in the northern hemisphere has declined to 2-4 mm per annum. The evapotranspiration rate was also noticed, with decreasing trend in New Zealand (18). However, the increased trend has been observed in various parts of the world, including South Africa (19), Peninsular Malaysia (20) and Iraq (21). The reference evapotranspiration dynamics in Heilongjiang Province were assessed using the Penman-Monteith method over 50 years. The sensitivity analysis demonstrated the more significant influence of wind speed on evapotranspiration rate; however, the factors driving evapotranspiration changes vary with climatic conditions (22).

Similarly, Bian et al. (23) investigated the annual and seasonal reference evapotranspiration trends over 46 years using weather data from 104 meteorological stations in Inner Mongolia. The findings exhibited the presence of an evaporation paradox with higher spatial variability in the study area. Additionally, wind and sunshine duration were identified as the dominant factors influencing the annual reference evapotranspiration changes. Similar results were reported in various locations in India (24). The yearly increase in reference evapotranspiration at the rate of 1.4 mm was noticed in the Three-River Headwaters regions of China (25). The spatial and temporal distribution of evapotranspiration across different areas is primarily influenced by climatic factors such as temperature, wind speed, rainfall and duration of sunshine. However, the dominant factors influencing evapotranspiration dynamics vary significantly depending on geographical location. (10, 14, 16).

The Lower Bhavani Basin is a crucial hydrological unit in Tamil Nadu, supporting diverse ecosystems and agricultural activities. The basin is experiencing moderate rainfall of 666.84 mm with high evapotranspiration rates, substantially impacting the hydrological cycle. The spatial and temporal distribution of evapotranspiration is primarily influenced by climate change, ultimately determining the availability and distribution of water resources at regional and global scales. Therefore, the study was conducted to assess the dynamics of reference evapotranspiration in the Lower Bhavani Basin, aiming to understand climate change's impact and provide crucial insights for effective water resources planning and management.

Materials and Methods

Study area

The Lower Bhavani Basin is situated between latitudes 11.2463°N and 11.7744°N and longitudes 77.0676°E and 77.6850°E in the western region of Tamil Nadu (Fig. 1). The basin predominantly covers significant portions of the Erode district, with some regions of Coimbatore and Tiruppur districts. It encompasses a total geographical area of approximately 2402 km^2 with an elevation ranging from 154 to 1669 m above sea level. The basin supports a diverse ecosystem, including forest areas, agricultural lands, human settlements, water bodies and barren lands, which are crucial in the region's hydrology. Moreover, it is characterized by a semi-arid climate, which has more variability to climate change and serves as a suitable study area for examining the dynamics of reference evapotranspiration under changing climatic conditions.

Data sources

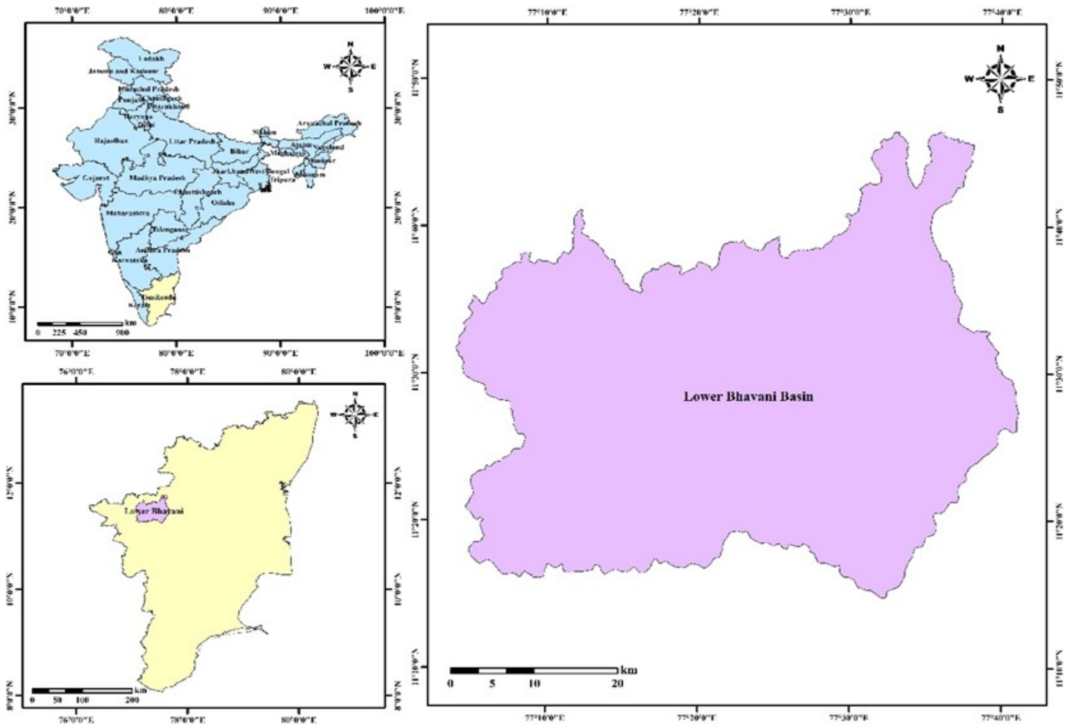

Fig. 1. Location map of the study area

Daily reference evapotranspiration with a spatial resolution of approximately 10 km is provided by the United Nations Food and Agriculture Organization (FAO). The FAO computes reference evapotranspiration using meteorological variables from the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) datasets. FAO 56-Penman-Monteith method derived reference evapotranspiration data was obtained using the AQUASTAT Climate Information Tool (https://aquastat.fao.org/climate-information-tool/) for the study area, which encompasses 27 grids. The monthly ET_0 was downloaded for 23 years (2000-2022), offering a comprehensive framework for assessing the variability and trends of reference evapotranspiration in the basin.

Trend analysis

Trend analysis is a crucial method in hydrological studies, which is essential for effectively planning and managing water resources. The study was carried out to assess the annual and seasonal dynamics of reference evapotranspiration using various nonparametric tests. The study area comprises four seasons: southwest monsoon (June-September), northeast monsoon (October-December), winter (January-February) and summer (March-May) (26). Trend analysis was carried out using R software 4.4.1 version and significance was tested at 5%.

Mann–Kendall Test

The Mann-Kendall test is a widely used nonparametric statistical method to investigate the trend of time series data (27, 28), particularly in hydrological and environmental studies (29, 30). The test is advantageous because it does not assume any specific distribution of the data and is resistant to the influence of outliers, making it suitable for various types of trend analysis. It is designed to assess the presence of a monotonic trend in a time series dataset. Mann-Kendall test assumes two hypotheses: randomly ordered data and time series data have a monotonic trend. The Mann-Kendall S statistic is computed using the following formula, which shows the number of positive and negative differences between data pairs.

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} \text{sign}\,(x_j - x_i) \qquad \text{Eqn.01}$$

where, χ_j and χ_i are the data points at time j and i, respectively, n is the length of the time series and sign (χ_j - χ_i) is the function that returns +1 if $\chi_j > \chi_i$, 0 if $\chi_j = \chi_i$, and -1 if $\chi_j < \chi_i$.

Moreover, tied values in time series data affect the distribution of S statistic and variance needs to be computed as follows,

$$\text{Var}(S) = \frac{n(n+1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \qquad \text{Eqn.02}$$

where n represents the number of data points, m is the number of tied groups, and t_i is the number of tied values in the i^{th} tied group. Similarly, the test statistic (Z) is calculated using the following formula to determine the significance of the trend.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\text{Var}(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\text{Var}(S)}}, & \text{if } S < 0 \end{cases} \qquad \text{Eqn.03}$$

Sen's slope estimator

The Sen's slope estimator is a nonparametric method used in trend analysis, particularly for estimating the slope of the trend in time series data (31). It is robust against extreme values and does not require the data to satisfy the specific distribution assumptions. Sen's slope estimator computes the slope as the median of all possible slopes between pairs of the observations in the dataset. It was used to study the magnitude of reference evapotranspiration trends in the study area.

$$\text{Slope } (\beta) = \text{Median } \left(\frac{x_i - x_j}{i - j}\right) \text{ for all } i > j \qquad \text{Eqn.04}$$

where, χ_j and χ_i denotes the ET_0 values in years i and j, respectively.

Change point analysis

Pettit's test is a statistical method used to detect the change point where the median of the time series data shifts significantly (32). It is a nonparametric test, mainly employed to identify the abrupt changes in the mean of the time series data. The change point analysis of annual and seasonal reference evapotranspiration datasets was conducted using R software. The test statistic ($U_{t,k}$) is calculated as follows,

$$U_{t,k} = \sum_{i=1}^{k} \sum_{j=k+1}^{n} \text{sign } (x_j - x_i) \qquad \text{Eqn.05}$$

where, χ_j and χ_i represents the data points at time j and i, respectively, k is the year in which change takes place, t is the length of the time series and sign (χ_j - χ_i) is the function that returns +1 if χ>0, 0 if χ= 0 and -1 if χ<0.

Subsequently, the Pettitt test detects the possible change point (K_T) where the absolute value of $U_{t,K}$ is maximized.

$$K_T = \max_{1 \le k < n} \left| U_{t,k} \right| \qquad \text{Eqn.06}$$

The significance of the change point is statistically evaluated using approximate p-value and indicates the presence of data shift when P > 0.05 or vice versa.

$$P \approx 2\exp \left[\left(-6U^2 \left(K_T\right)\right) / \left(n^3 + n^2\right)\right] \qquad \text{Eqn.07}$$

Principal component analysis

Principal component analysis (PCA) is a multivariate statistical technique used to reduce the dimensionality of variables while retaining most of their variability (33). It transforms the dataset into a set of uncorrelated variables called principal components, which are ordered by the level of variance. PCA was performed using R software to study the weather variables influencing the reference evapotranspiration.

Relative moisture index

The Relative Moisture Index (RMI) is a critical parameter used to assess changes in wet conditions in the study area. The index represents moisture availability and is calculated using the following formula (34).

$$RMI = \frac{\text{Precipitation} - ET_0}{ET_0} \qquad \text{Eqn.08}$$

Interpolation of ET_0 and RMI

The inverse distance weighted method is commonly employed for spatial interpolating discrete variables (29, 35). It estimates the unknown values at specific locations using the values of nearby known points. The inverse distance weighted technique was used to produce the annual and seasonal maps of reference evapotranspiration and the relative moisture index using ArcGIS 8.4 software.

Results and Discussion

Trend analysis of reference evapotranspiration

The Lower Bhavani Basin's annual and seasonal reference evapotranspiration was investigated using descriptive statistics from 2000 to 2022 (Table 1). The results showed that the average reference evapotranspiration rate was 1672.87 mm per annum. Reference evapotranspiration varied with seasons (Fig. 2), with the southwest monsoon period exhibiting a higher rate of reference evapotranspiration (556.98 mm) followed by the summer season (513.96 mm). The winter period had a lower level of reference evapotranspiration (262.96 mm). A standard deviation of 48.61 mm indicates significant variation in annual reference evapotranspiration rates. The maximum (1780.81 mm) and minimum (1574.07 mm) reference evapotranspiration values were found in 2002 and 2004, respectively. Skewness helps to understand the asymmetry of the distribution of reference evapotranspiration over the years or across seasons. The positive skewness observed with annual and seasonal reference evapotranspiration, particularly during the southwest and northeast monsoon seasons, revealed moderate atmospheric demand and exhibited significantly higher evapotranspiration rates due to extreme weather conditions.

Conversely, the winter and summer periods were negatively skewed, implying higher atmospheric demand with occasional periods of lower demand due to cooler conditions. Similarly, annual and seasonal reference evapotranspiration were observed with kurtosis of less than 3, indicating evenly distributed data around the mean with fewer extreme values during the study period. November, during the winter season, recorded a lower amount of reference evapotranspiration (105.28 mm), whereas March, during the summer season, had the maximum reference evapotranspiration (173.36 mm).

The changes in evapotranspiration substantially affect soil moisture, rainfall patterns and hydrological cycle, which ultimately influence agriculture (11). Evapotranspiration directly impacts agriculture by influencing crop water demand, determining suitable crops for specific climates, influencing irrigation practices and affecting crop yield. For instance, climate change drives

Table 1. Descriptive analysis of ET_0 in the Lower Bhavani Basin (2000-2022)

Particulars	Annual	Southwest monsoon	Northeast monsoon	Winter	Summer
Mean	1672.87	556.98	338.96	262.96	513.96
Median	1665.22	559.04	336.44	265.37	520.96
Minimum	1574.07	506.33	295.52	235.22	476.04
Maximum	1780.81	621.63	393.59	281.07	540.48
Kurtosis	0.39	-0.62	1.16	0.97	-0.95
Skewness	0.24	0.10	0.53	-0.81	-0.53
Standard deviation	48.61	30.46	21.02	10.70	19.96
Coefficient of variation	2.91	5.47	6.20	4.07	3.88
Contribution (%)	100	33.29	20.26	15.72	30.72

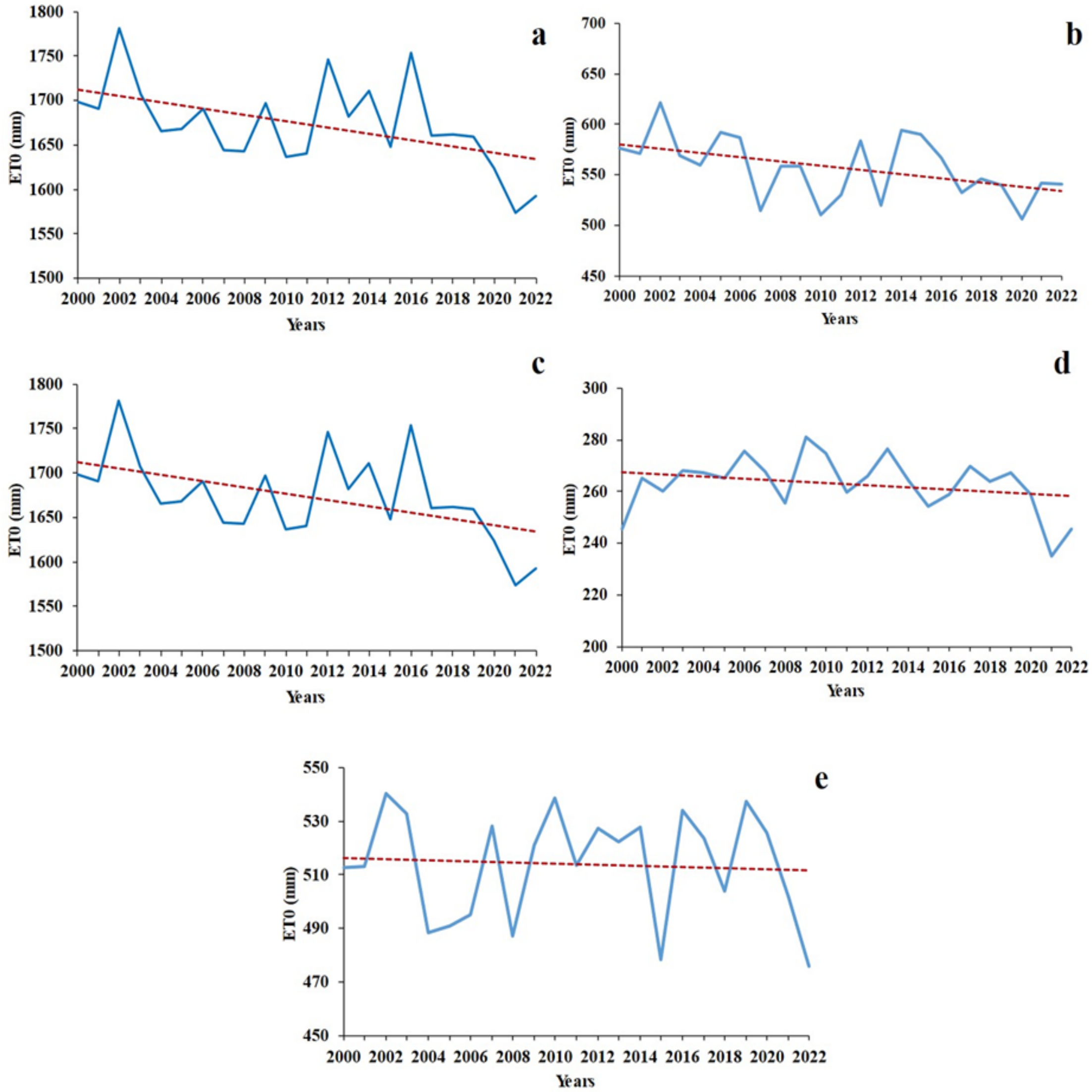

Fig. 2. Trend analysis of ET_0: (a) Annual (b) Southwest monsoon (c) Northeast monsoon (d) Winter (e) Summer

higher evapotranspiration rates and adaptive strategies such as precision irrigation and drought-resistant crops become increasingly crucial for maintaining agricultural productivity. Hence, analyzing changes about evapotranspiration is crucial in climate change. The nonparametric test was employed to assess the temporal trends of reference evapotranspiration, with results presented in Table 2. The Mann-Kendall test showed negative values, representing a decreasing trend in annual and seasonal reference evapotranspiration. In addition, the Sen slope estimator provides the direction and magnitude of changes in reference evapotranspiration. The yearly and southwest monsoon reference evapotranspiration decreased significantly, with p-values less than 0.05. The reference evapotranspiration in the basin was found to be decreasing annually at the rate of 3.53 mm. Further, reference evapotranspiration during northeast monsoon, winter and summer was noted with a decreasing trend; however, it was statistically non-significant.

Change point analysis was performed using Pettitt's test to identify when a shift occurred in annual and seasonal reference evapotranspiration. The result demonstrated the abrupt changes in annual reference evapotranspiration in 2016, making the beginning of the decreasing trend (Fig. 3). Similarly, the trend change point for the southwest monsoon, the northeast monsoon, winter and summer

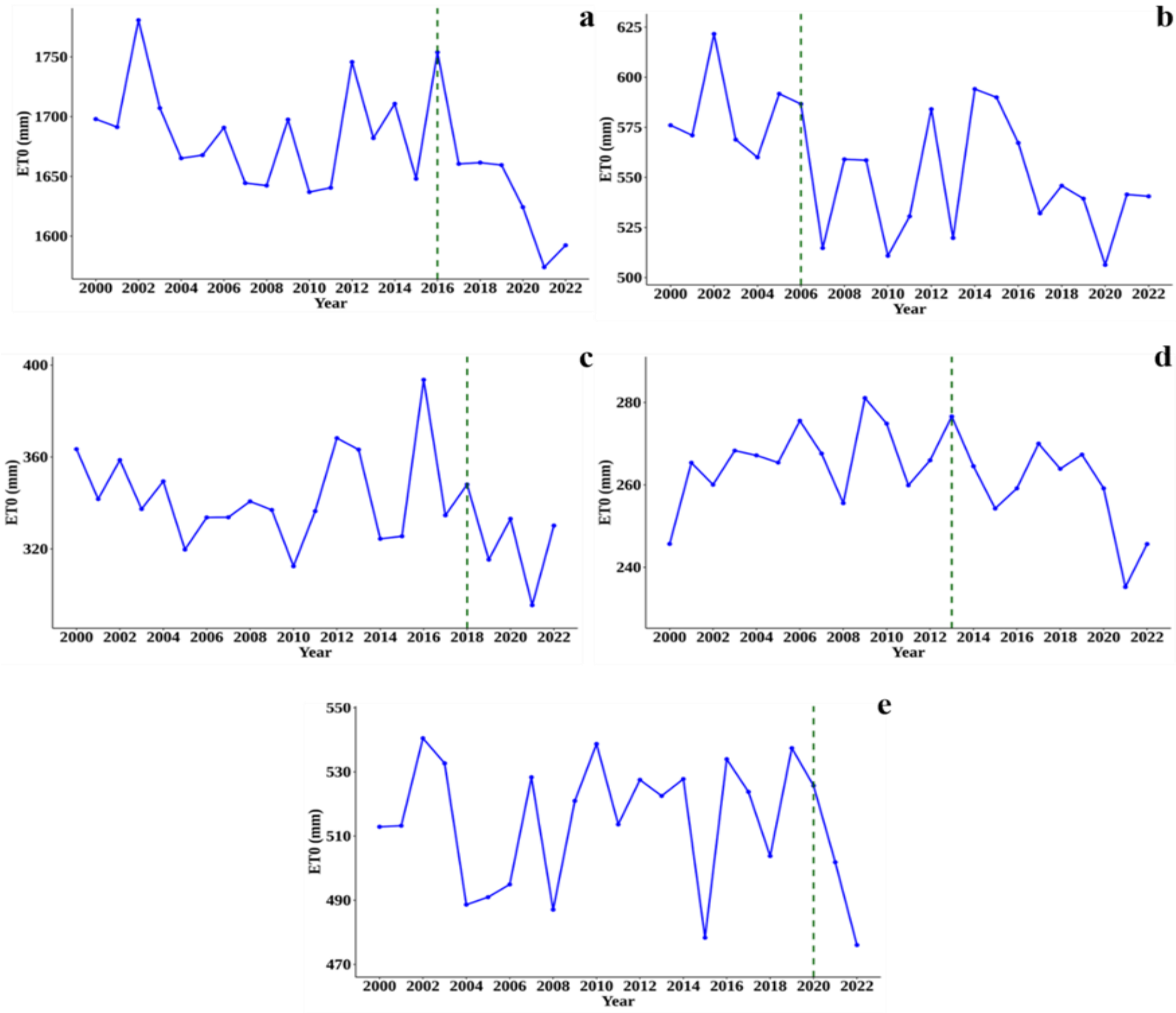

Fig. 3. Detection of change point in ET_0 trend in the Lower Bhavani Basin: (a) Annual (b) Southwest monsoon (c) Northeast monsoon (d) Winter (e) Summer

Table 2. Trend analysis of annual and seasonal ET_0 in the study area

Particulars	Mann-Kendall Test (Z)	Sen Slope (β)	p-value	Trend
Annual	-0.375	-3.529	0.013	Decreasing
Southwest monsoon	-0.328	-1.915	0.030	Decreasing
Northeast monsoon	-0.281	-1.019	0.065	Decreasing
Winter	-0.182	-0.327	0.235	Decreasing
Summer	-0.028	-0.181	0.874	Decreasing

were 2006, 2018, 2013 and 2020, respectively.

The study comprehensively analyzed changes in reference evapotranspiration in the Lower Bhavani Basin over 23 years under a changing climate scenario. The nonparametric test was conducted to determine the magnitude and direction of the evapotranspiration trend. The Mann-Kendall test neglects short-term and long-term autocorrelation in time series data, which has greater significance in trend detection (10). The method disregards the variability in weather variables and accurately determines the trend's magnitude. The regions with diversified landscapes, like Lower Bhavani Basin, exhibited substantial variation in annual and seasonal reference evapotranspiration. Similar results were reported in different areas worldwide and significantly influenced by weather variables (14, 25, 35). Research studies have reported a decreasing trend in reference evapotranspiration with increasing temperature (20, 24, 36, 37). Similarly, the basin showed a decreasing trend in annual and seasonal reference evapotranspiration, exhibiting the evaporation paradox. Furthermore, significant changes were observed in annual and southwest monsoon evapotranspiration rates, indicating the need to study the effect of weather factors on evapotranspiration.

Relationship between weather parameters and evapotranspiration

The correlation study provides detailed insights into the effects of weather variables on reference evapotranspiration. It was observed that weather variables such as rainfall, temperature, solar radiation, wind speed and relative humidity were significantly correlated with reference evapotranspiration (Fig. 4). However, the magnitude of the relationship varied and affected the evapotranspiration process. The air temperature and solar radiation exhibited a high positive correlation, indicating that reference evapotranspiration increases with temperature and solar radiation. The energy available for both soil evaporation and plant transpiration increases with rising air temperature and solar radiation, which intensifies the processes and

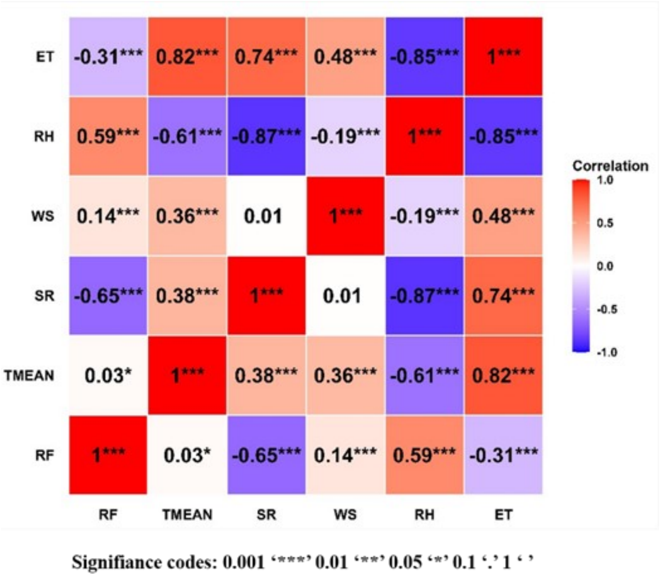

Fig. 4. Correlation analysis between weather variables and ET_0

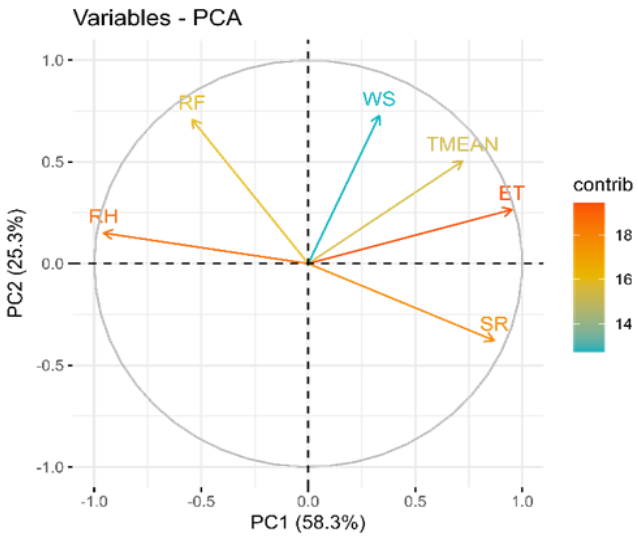

Fig. 5. PCA analysis of weather variables in the study area

directly leads to a higher rate of reference evapotranspiration (38). In addition, reference evapotranspiration was negatively correlated with relative humidity, while a positive correlation was observed with wind speed. Rainfall had a minimum effect on reference evapotranspiration and decreased the reference evapotranspiration rates to a lesser extent in the basin.

Principal component analysis was performed to determine the weather variables significantly influencing reference evapotranspiration. It can be identified by examining the contribution to the principal component (PC) that is highly correlated with reference evapotranspiration. Moreover, principal component analysis transforms correlated variables into a set of uncorrelated variables, which helps to understand the effect of weather variables on reference evapotranspiration without multicollinearity. The results showed that PC 1 and PC 2 were important components, which explained 83.60 per cent of the variance in the original data (Fig. 5). PC1 typically described that evapotranspiration in the Lower Bhavani Basin increases with solar radiation and temperature. In addition, PC1 revealed a negative relationship between reference evapotranspiration and relative humidity. It confirmed that weather variables such as temperature, solar radiation and relative humidity are the factors that drive the evapotranspiration in the basin. Similarly, PC2 showed that higher wind speed and rainfall reduce reference evapotranspiration, mainly when air temperature is lower. It is inferred that increased precipitation with strong wind velocity and lower temperature is less conducive to accelerating the evapotranspiration process due to increased moisture availability and reduced atmospheric demand.

The research findings underscore that weather variables directly influence the annual and seasonal trends of reference evapotranspiration in the basin. The effect of each weather variable on reference evapotranspiration was assessed in the study, and identified that temperature, solar radiation and relative humidity were the major driving factors of reference evapotranspiration in the study area. The result was consistent with previous research findings (14, 19, 38). Solar radiation is the primary energy source that accelerates the evapotranspiration process. The decreased trend in solar radiation in the basin was typically observed among weather parameters, which attributed to decreased reference evapotranspiration rate, as less energy is available to accelerate the process. The increased cloud cover reduces the duration of sunshine and solar radiation that reaches the Earth's surface, which has been reported in India (24) and different parts of the northern hemisphere (14, 39).

The interpolation of reference evapotranspiration was performed and generated the maps to understand the dynamics of spatial reference evapotranspiration across different seasons (Fig. 6). The spatial distribution of annual reference evapotranspiration was noted with significant variations in the basin. The zonal statistics tool in Arc GIS software was used to determine the average, minimum and maximum reference evapotranspiration over different seasons in the basin (Table 3).

The winter season recorded lower rates of average reference evapotranspiration (262.81 mm), which can be attributed to lower air temperature and the southwest monsoon (555.42 mm) and the summer (513.77 mm) seasons recorded higher average reference evapotranspiration

Table 3. Spatial distribution of ET_0 in the Lower Bhavani Basin

Particulars	Minimum ET_0(mm)	Maximum ET_0(mm)	Average ET_0(mm)	Standard Deviation
Annual	1460.87	1939.70	1670.28	111.19
Southwest monsoon	478.97	661.77	555.42	37.98
Northeast monsoon	293.05	391.59	338.28	24.39
Winter	233.18	307.86	262.81	21.27
Summer	455.20	587.45	513.77	29.63

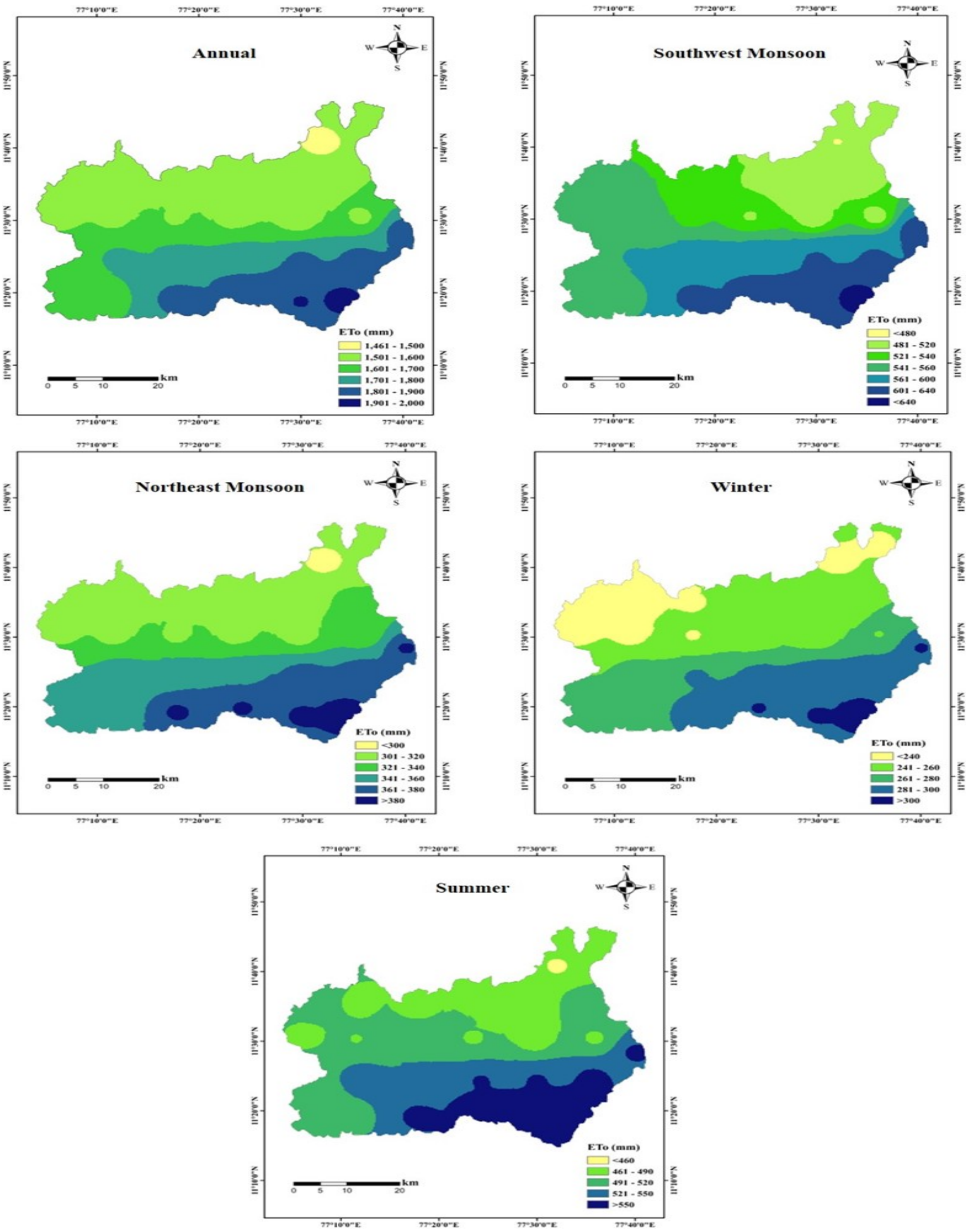

Fig. 6. Spatial distribution of annual and seasonal ET_0 in the Lower Bhavani Basin

among the seasons. The higher temperature, reduced relative humidity and increased availability of solar radiation at Earth's surface during the southwest monsoon and summer elevated the reference evapotranspiration rates. The moderate reference evapotranspiration (333.28 mm) was found during the northeast monsoon, substantially influenced by temperature, rainfall, cloud cover and wind velocity.

Similarly, the relative moisture index was computed to assess the dry and wet conditions across the basin. The mean annual relative moisture index was -0.20 in the Lower Bhavani Basin and unevenly distributed due to spatial variations in evapotranspiration rates (Table 4). It demonstrated that basins have arid or semi-arid climates and could experience dry conditions in a year (Fig. 7). Similarly, the relative moisture index noticed during winter and summer seasons was negative, indicating that dry conditions prevailed during the seasons. However, the monsoon period had positive values in various parts of the basin, implying that sufficient moisture was available to meet the atmospheric demand (14, 38). It was attributed to assured water availability by monsoon rainfall during the periods. The insights from the analysis highlight the need for more dynamic and adaptive irrigation practices. The policymakers should encourage the implementation of evapotranspiration-based irrigation systems, which adjust water application rates based on real-time weather conditions. It would optimize water use in agriculture at the

Table 4. Spatial distribution of RMI in the study area

Particulars	Minimum RMI	Maximum RMI	Average RMI	Standard Deviation
Annual	-0.37	-0.06	-0.20	0.08
Southwest monsoon	-0.16	0.58	0.22	0.22
Northeast monsoon	-0.01	0.48	0.24	0.10
Winter	-0.93	-0.88	-0.90	0.01
Summer	-0.70	-0.41	-0.58	0.06

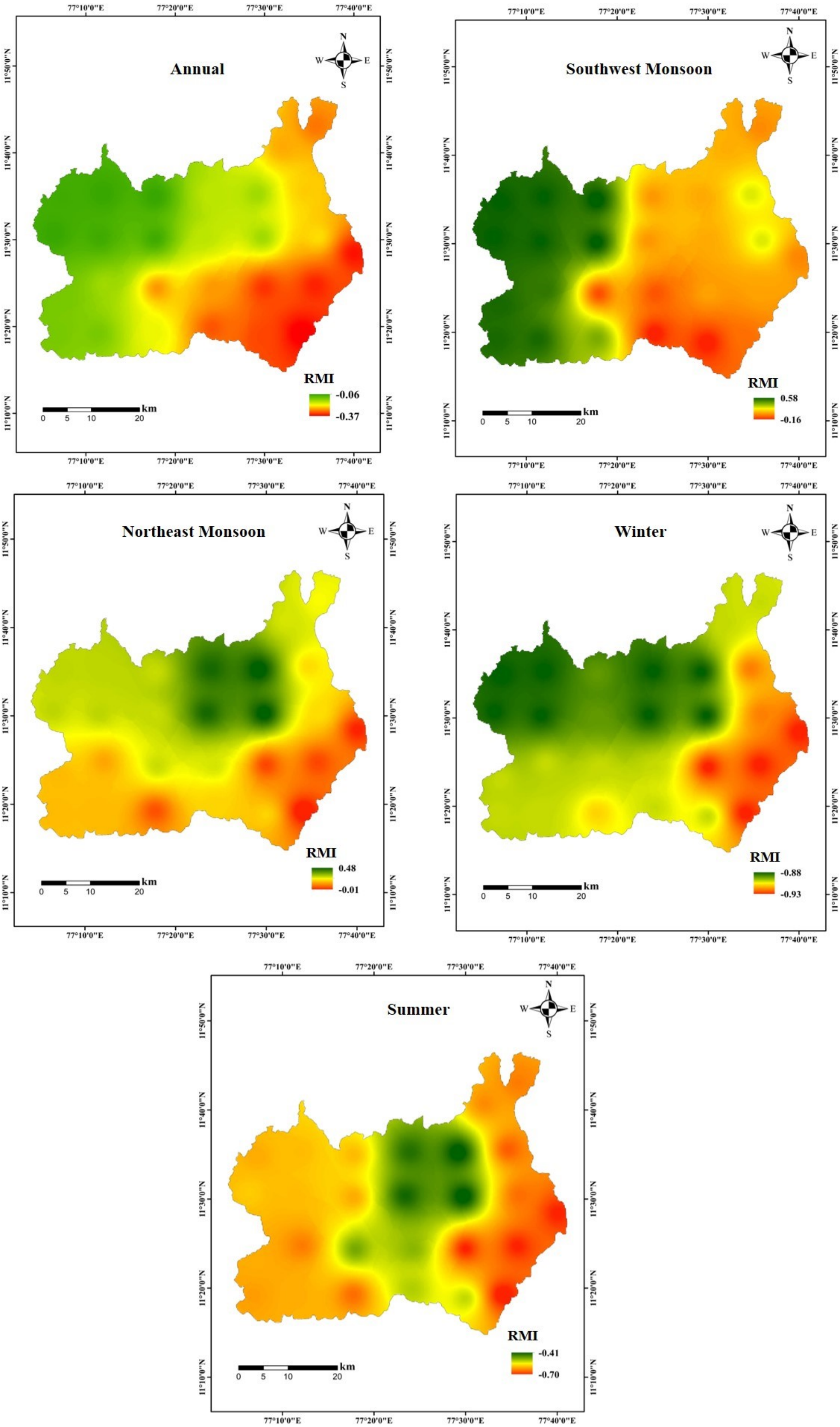

Fig. 7. Annual and seasonal RMI in the study area

basin level and ensure efficient water resource management.

Conclusion

The present study assessed the trends of annual and seasonal reference evapotranspiration in the Lower Bhavani Basin over 23 years and provided critical insights into the basin's hydroclimatic dynamics. The findings showed a decreasing trend in both annual and seasonal reference evapotranspiration, exhibiting a phenomenon called evaporation paradox. Additionally, the study revealed that weather factors such as solar radiation, temperature and relative humidity significantly influence evapotranspiration. The decrease in reference evapotranspiration with an increase in temperature poses significant implications for water resources management. Lower evapotranspiration rates result in increased surface water availability due to reduced atmospheric demand; however, it could adversely affect the hydrological cycle of the basin. The shift in evapotranspiration trends necessitates careful consideration during water allocation, storage and distribution in the basin.

Moreover, the research findings are highly significant to agriculture. The decrease in reference evapotranspiration resulted in lower crop water demand, potentially reducing the irrigation requirement. The study also demonstrated that dry conditions prevailed predominantly in the Lower Bhavani Basin, as evidenced by the results of the relative moisture index. It indicated that agriculture in the basin is vulnerable to drought and water scarcity, particularly during summer and winter. Additionally, wet conditions prevailed during the monsoon period, suggesting that water management practices need to focus on water harvesting and storage to sustain agricultural activities during dry periods. Moreover, the study's findings pave the way for future research to refine understanding the complex relationships among climate change, evapotranspiration and hydrological cycles. It is critical for developing adaptive strategies that ensure sustainable agricultural production and regional water security.

Acknowledgements

The authors thank the Centre for Water and Geospatial Studies, Tamil Nadu Agricultural University, Coimbatore, for extending their guidance and technical assistance in conducting this research.

Authors' contributions

PP: Conceptualization, Methodology, Writing - Original draft, Data Curation, Formal Analysis. SP: Conceptualization, Methodology, Supervision, Writing - Review & Editing. APS: Data Curation, Writing - Original draft. KPR: Visualization, Formal Analysis. SSK: Writing - Review & Editing. KV: Visualization. SS: Resources. PS: Writing - Review & Editing.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Lee H, Calvin K, Dasgupta D, Krinner G, Mukherji A, et al. Climate change 2023: synthesis report. Contribution of working groups I, II and III to the sixth assessment report of the intergovernmental panel on climate change. The Australian National University; 2023. https://doi.org/10.59327/IPCC/AR6-9789291691647.001
2. Yang D, Yang Y, Xia J. Hydrological cycle and water resources in a changing world: A review. Geography and Sustainability. 2021;2 (2):115-22. https://doi.org/10.1016/j.geosus.2021.05.003
3. Li ZL, Tang R, Wan Z, Bi Y, Zhou C, et al. A review of current methodologies for regional evapotranspiration estimation from remotely sensed data. Sensors. 2009;9(05):3801-53. https://doi.org/10.3390/s90503801
4. Abtew W, Melesse A. Climate change and evapotranspiration. In: Abtew W, Melesse A, editor. Evaporation and evapotranspiration Measurements and estimations. Dordrecht; 2013. p. 197-202. https://doi.org/10.1007/978-94-007-4737-1_13
5. Yang Z, Liu Q, Cui B. Spatial distribution and temporal variation of reference evapotranspiration during 1961-2006 in the Yellow River Basin, China. Hydrological Sciences Journal. 2011;56(6):1015-26. https://doi.org/10.1080/02626667.2011.590810
6. Anabalón A, Sharma A. On the divergence of potential and actual evapotranspiration trends: An assessment across alternate global datasets. Earth's Future. 2017;5(9):905-17. https://doi.org/10.1002/2016EF000499
7. Li C, Wu PT, Li XL, Zhou TW, Sun SK, et al. Spatial and temporal evolution of climatic factors and its impacts on potential evapotranspiration in Loess Plateau of Northern Shaanxi, China. Science of the Total Environment. 2017;589:165-72. https://doi.org/10.1016/j.scitotenv.2017.02.122
8. Allen RG, Pereira LS, Raes D, Smith M. FAO Irrigation and drainage paper No. 56. Rome: Food and Agriculture Organization of the United Nations. 1998;56(97):e156.
9. Singer MB, Asfaw DT, Rosolem R, Cuthbert MO, et al. Hourly potential evapotranspiration at 0.1 resolution for the global land surface from 1981-present. Scientific Data. 2021;8(1):224. https://doi.org/10.1038/s41597-021-01003-9
10. Ahmed K, Shahid S, Chung ES, Nawaz N, et al. Divergence of potential evapotranspiration trends over Pakistan during 1967-2016. Theoretical and Applied Climatology. 2020;141:215-27. https://doi.org/10.1007/s00704-020-03195-3
11. Xiang K, Li Y, Horton R, Feng H. Similarity and difference of potential evapotranspiration and reference crop evapotranspiration-a review. Agricultural Water Management. 2020;232:106043. https://doi.org/10.1016/j.agwat.2020.106043
12. Pereira LS, Allen RG, Smith M, Raes D. Crop evapotranspiration estimation with FAO56: Past and future. Agricultural water management. 2015;147:4-20. https://doi.org/10.1016/j.agwat.2014.07.031
13. You G, Arain MA, Wang S, Lin N, et al. Trends of actual and potential evapotranspiration based on Bouchet's complementary concept in a cold and arid steppe site of Northeastern Asia. Agricultural and Forest Meteorology. 2019;279:107684. https://doi.org/10.1016/j.agrformet.2019.107684
14. Zheng Q, He J, Qin M, Wu X, Liu T, Huang X. Spatiotemporal variation of potential evapotranspiration and its dominant factors during 1970- 2020 across the Sichuan-Chongqing region, China. Plos One. 2022;17(6). https://doi.org/10.1371/journal.pone.0268702
15. Das S, Datta P, Sharma D, Goswami K. Trends in temperature,

precipitation, potential evapotranspiration, and water availability across the Teesta River Basin under 1.5 and 2˚C temperature rise scenarios of CMIP6. Atmosphere. 2022;13(6):941. https://doi.org/10.3390/atmos13060941

16. Zuo D, Xu Z, Yang H, Liu X. Spatiotemporal variations and abrupt changes of potential evapotranspiration and its sensitivity to key meteorological variables in the Wei River basin, China. Hydrological Processes. 2012;26(8):1149-60. https://doi.org/10.1002/hyp.8206
17. Chu R, Li M, Islam AR, Fei D, Shen S. Attribution analysis of actual and potential evapotranspiration changes based on the complementary relationship theory in the Huai River basin of eastern China. International Journal of Climatology. 2019;39(10):4072-90. https://doi.org/10.1002/joc.6060
18. Roderick ML, Farquhar GD. Changes in New Zealand pan evaporation since the 1970s. International Journal of Climatology: A Journal of the Royal Meteorological Society. 2005;25(15):2031-9. https://doi.org/10.1002/joc.1262
19. Ndiaye PM, Bodian A, Diop L, Deme A, et al. Trend and sensitivity analysis of reference evapotranspiration in the Senegal river basin using NASA meteorological data. Water. 2020;12(7):1957. https://doi.org/10.3390/w12071957
20. Yong SL, Ng JL, Huang YF, Ang CK. Innovative trend analysis of reference crop evapotranspiration in peninsular Malaysia. InIOP Conference Series: Earth and Environmental Science 2022 May 1 (Vol. 1022, No. 1, p. 012071). IOP Publishing. https://doi.org/10.1088/1755-1315/1022/1/012071
21. Al-Hasani AA, Shahid S. Spatial distribution of the trends in potential evapotranspiration and its influencing climatic factors in Iraq. Theoretical and Applied Climatology. 2022;150(1):677-96. https://doi.org/10.1007/s00704-022-04184-4
22. Nie T, Yuan R, Liao S, Zhang Z, et al. Characteristics of potential evapotranspiration changes and its climatic causes in Heilongjiang Province from 1960 to 2019. Agriculture. 2022;12(12):2017. https://doi.org/10.3390/agriculture12122017
23. Bian Y, Dai H, Zhang Q, Yang L, Du W. Spatial distribution of potential evapotranspiration trends in the Inner Mongolia Autonomous Region (1971–2016). Theoretical and Applied Climatology. 2020;140:1161-9. https://doi.org/10.1007/s00704-020-03154-y
24. Verma IJ, Jadhav VN, Erande RS. Recent variations and trends in potential evapotranspiration (PET) over India. Mausam. 2008;59(1):119-28. https://doi.org/10.54302/mausam.v59i1.1217
25. Wen X, Pan W, Sun X, Li M, Luo S, et al. Study on the variation trend of potential evapotranspiration in the three-river headwaters region in China over the past 20 years. Frontiers in Earth Science. 2020;8:582742. https://doi.org/10.3389/feart.2020.582742
26. Rajavel M, Vengateswari M, Geethalakshmi V, Bhuvaneswari K, Vakeswaran V, et al. Effect of ENSO on Seasonal Temperature Over Tamil Nadu. International Journal of Environment and Climate Change. 2022;12(10):1210-21. https://doi.org/10.9734/IJECC/2022/v12i1030918
27. Mann HB. Nonparametric tests against trend. Econometrica: Journal of the econometric Society. 1945:245-259. https://doi.org/10.2307/1907187
28. Kendall MG. Rank Correlation Methods. New York; 1975
29. Kumar A, Kumar S, Rautela KS, Shekhar S, et al. Assessing seasonal variation and trends in rainfall patterns of Madhya Pradesh, Central India. Journal of Water and Climate Change. 2023;14(10):3692-712. https://doi.org/10.2166/wcc.2023.280
30. Onyutha C. Statistical analyses of potential evapotranspiration changes over the period 1930-2012 in the Nile River riparian countries. Agricultural and Forest Meteorology. 2016;226:80-95. https://doi.org/10.1016/j.agrformet.2016.05.015
31. Sen PK. Estimates of the regression coefficient based on Kendall's tau. Journal of the American statistical association. 1968;63(324):1379-89.
32. Pettitt AN. A nonparametric approach to the change-point problem. Journal of the Royal Statistical Society: Series C (Applied Statistics). 1979;28(2):126-35. https://doi.org/10.2307/2346729
33. Abdi H, Williams LJ. Principal component analysis. Wiley interdisciplinary reviews: computational statistics. 2010;2(4):433-59. https://doi.org/10.1002/wics.101
34. Zheng K, Chen C, Luo G, Gao C. Research of the agriculture drought and association with meteorological drought - a case study of above the Bengbu sluice in the Huaihe River Basin, China. Theoretical and Applied Climatology. 2022;147(1):1-2. https://doi.org/10.1007/s00704-021-03671-4
35. Rahman MA, Yunsheng L, Sultana N, Ongoma V. Analysis of reference evapotranspiration (ET 0) trends under climate change in Bangladesh using observed and CMIP5 data sets. Meteorology and Atmospheric Physics. 2019;131:639-55. https://doi.org/10.1007/s00703-018-0596-3
36. Azizzadeh M, Javan K. Analyzing trends in reference evapotranspiration in northwest part of Iran. Journal of Ecological Engineering. 2015;16(2):1-12. http://dx.doi.org/10.129112F22998993%2F1853
37. Jiao L, Wang D. Climate change, the evaporation paradox, and their effects on streamflow in Lijiang watershed. Polish Journal of Environmental Studies. 2018;27(6):2585-2591. https://doi.org/10.15244/pjoes/81290
38. Zhang H, Wang L. Analysis of the variation in potential evapotranspiration and surface wet conditions in the Hancang River Basin, China. Scientific Reports. 2021;11(1):8607. https://doi.org/10.1038/s41598-021-88162-2
39. Liu B, Xu M, Henderson M, Gong W. A spatial analysis of pan evaporation trends in China, 1955-2000. Journal of Geophysical Research: Atmospheres. 2004;109(D15). https://doi.org/10.1029/2004JD004511