Projected Shifts in Potential Evapotranspirationunder the Impact of Climate Changefor India and Karnataka: A Jensen-Haise approach.

ABSTRACT

Climate change, driven by long-term shifts in weather patterns caused by greenhouse gas emissions, has profound effects on agriculture, particularly crop production, which is highly dependent on weather conditions. Changes in rainfall patterns and rising temperatures can significantly reduce crop yields, especially in subtropical regions like India. Elevated levels of CO_2 and temperature influence key biological processes such as respiration, photosynthesis, plant growth, reproduction, and water use. One crucial aspect of crop management affected by climate change is evapotranspiration, which plays a central role in the soil-plant-atmosphere water balance and determines irrigation frequency. Potential Evapotranspiration (PET) refers to the total water loss through the combined processes of transpiration and evaporation, both of which are governed by weather factors such as temperature, humidity, solar radiation, and wind. PET is an important indicator of the water that needs to be replenished through rainfall or irrigation, and its estimation is critical for calculating crop water requirements and adjusting irrigation schedules to maximize water efficiency. As climate change intensifies, it is essential to estimate PET for various crops, cropping systems, and agro-ecosystems over the coming decades to ensure effective crop and resource management. This study estimates PET for India, including Karnataka, from 2021 to 2070 using the Jensen-Haise method. The results show a mix of increasing and decreasing trends in annual PET, but an overall slight upward trend is projected over the 50-year period. The average annual PET for Karnataka is estimated at 2,516 mm/year, with an increasing trend expected in the next five decades. The highest monthly PET values are predicted for April (279.30 mm), May (307.46 mm), and June (319.36 mm). These projected increases in PET must be factored into crop selection, cropping systems, and water management plans to ensure sustainable crop yields and improved water use efficiency in the face of climate change.

Keywords: Climate change, Jensen-Haise method, Menn-Kendall non-parametric test, Potential Evapotranspiration, Trend analysis.

1. INTRODUCTION

Climate is the most important determinant of crop productivity, especially in countries like India, where rain-fed agriculture accounts for roughly two-third of the total cultivated area. As a result, change in climate is a major concern, with large-scale direct and indirect effects on agriculture. The change in climate is likely to have a profound effect on hydrological cycle viz. precipitation, evapotranspiration, soil moisture etc. Evapotranspiration (Goyal, 2004) and it manifests as an increase in global temperature, change in rainfall amount, increased intensity of rainfall, rising sea level, glacier melting, shifts in crop growing season, and more frequent occurrences of extreme events such as dry spells, wet spells, drought and flood (Dinpashoh*et al.,* 2019).

Water resources and agriculture will be subject to various and complicated impacts due to climate change. It is clear that a changing climate will affect the soil's water balance, which will modify how much water evaporates and how much water transpires. A significant part of the water cycle and agricultural water balance is evapotranspiration (ET). Planning, managing, and regulating agricultural water resources depends on accurate estimates of water usage in agricultural areas as this enterprise consumed little over 80 % of the total fresh water in India. Hence, accurate estimates result in the creation of a sustainable water balance, reduces the effects of water shortage, and avoids wasting and/or overusing scarce water resources. Potential evapotranspiration (PET) is the maximum possible quantity of water that can be lost in vapour form from a large area of actively growing, uniformly tall grass that totally shades the ground in a given climate. (Gangopadhyay *et al.,* 1966; FAO, 1998). Empirical formulae are used to calculate PET (FAO, 1998).

PET is the sum of both evaporation from the soil surface and transpiration from plants when the water supply is unlimited. In other words, it is the maximum quantity of water capable of being lost as water vapour, under a given climate, by a continuous, extensive stretch of vegetation covering the ground, when there is no shortage of water.PET is influenced by several factors amongst which net solar radiation, relative humidity, air temperatures; wind speed, atmospheric aerosol (including dust particles), type and size of vegetative cover, availability of soil moisture, reflective land surface, and change in land use/land cover are the major factors.Several researchers elsewhere have investigated the effects of climate change on the variations in PET at spatial and temporal scales across different regions of the world. The performance of agricultural crops as well as hydrologic processes may get significantly influenced by long-term changes in PET(Zhang *et al.,* 2022; D'Odorico*et al.,* 2023 and Li *et al.,* 2023).

Researchers have also investigated the impact of various meteorological variables on the changes in PET and discovered that relative humidity and radiation are strongly associated with changes in PET when compared to other variables (McKenny and Rosenberg, 1993; Chattopadhyay and Hulme, 1997). Understanding the distribution of these changes, identifying the precise times when significant changes occur, and quantitatively estimating these changes are all necessary to comprehend the implications of long-term changes in PET on agriculture and water resources. Thus, an effort was made in this paper to examine recent variations and trends in PET using the linear trend analysis technique, in order to recognize the precise times when significant shifts take place and quantitatively estimate these changes.

2. MATERIALS AND METHODOLOGY

In the present study, PET for whole of India, State wise and specifically for Karnataka was calculated by using Jensen-Haise method for the projected period 2021 to 2070.India lies completely in the Northern and Eastern hemisphere between the latitudes 84º N and 37 º 6’ N, and longitudes 68 º 7′ E and 97 º 25′ E. The total area of India is 3.28 m sq. km and it is divided into 28 states and 8 union territories.Karnataka is one of the states of India located between 11°30' N and 18 º 30' N latitudes, and between 74 º E and 78 º 30' E longitude. Karnataka is situated on a tableland where the Western Ghats and Eastern Ghats converge into the complex, in the western part of the Deccan Peninsular region of India.

Jensen-Haise method

It is a temperature based PET equation.Jensen and Haise (1963) derived this evapotranspiration equation based on the relationship using mean air temperature and solar radiation.A Jensen-Haise method that solves the problem of calculating the amount of PET is needed. Because the method used for calculation is empirical, it must be supported by software that facilitates the simulation of gravity and the calculation of evaporation amounts under the influence of climate change.

It is expressed as;

$$\mathbf{PET = (0.025 * T + 0.08)\ Rs}$$

Where,

PET = Potential evapotranspiration (mm/day)

T =Mean air temperature in (°C).

Rs =Short wave incoming solar radiation (W/m^2)

The daily data for the study at a resolution of 0.5□ x 0.5□ were downloaded from the Coupled Model Inter Comparison Project 5 (CMIP-5). The CMIP5 provides daily climate projections on single levels from a large number of experiments, models, members and times computed in the framework of the fifth phase of the Coupled Model Intercomparison Project (CMIP5);https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cmip5monthly-single-levels?tab=overview. The downloaded data were processed using ferret software (https://ubuntu.com/).

Then, the non-parametric Mann-Kendall (MK) test was applied to detect trends. Mann- Kendall trend test was adopted for testing the significance of trend. It's a statistical test widely used to analyse trend in climatologic and hydrologic time series data, and were tested for the significance at 95 % level.

The study focuses on India, with particular emphasis on Karnataka, a state characterized by diverse climatic conditions ranging from arid to humid zones. The Jensen-Haise method was used to estimate Potential Evapotranspiration (PET) based on solar radiation and temperature data for the period 2021–2070. The method integrates key climate variables to project PET values. To analyze long-term trends, the Mann-Kendall test, a non-parametric method, was employed to detect significant trends in the projected PET data. This approach allowed for the evaluation of annual and monthly PET changes, providing insights into future water demands and crop management needs under changing climatic conditions.

The slopes of trend lines were estimated using Sen's estimator approach as given below.

$$S_0 = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\ (xj - xk)$$

Where, n is the number of observed data series, xj and xi are the values in period j and i respectively, and j>i.

The spatial and temporal patterns of the changes in PET for India and state wise were estimated. For this, the spatial map was generated by using ARC GIS 10.8 software (https://desktop.arcgis.com/en/arcmap/latest/get-started/installation-guide/installing-on-your-computer.htm).ArcGIS is a cloud-based mapping and analysis solution, which is used to make maps and to analyse spatial and temporal data.

3. RESULTS

3.1. Variations and trends in mean annual PET over India for the period 2021-2070

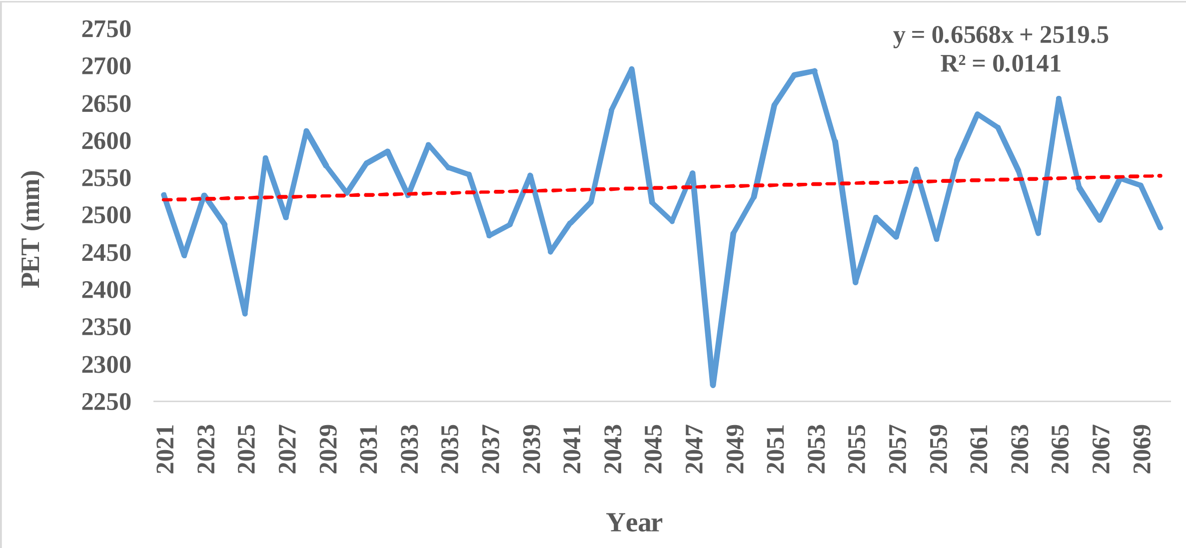

Fig. 1. Trends in mean annual PET over India for the period 2021-2070

Analysis of variations and trends in mean annual PET over India for projected period of next 50 years (2021-2070) was derivedby Jensen-Haise method. The PET values here are affected by two factors: mean air temperature (Ta) and Short wave incoming solar radiation (Rs). From the fig.1 it can been observed that mean annual PET values showed increasing and decreasing trend over time, but overall for the next 50 years slightly increasing trend was seen. The highest mean annual PET is expected to be in the year 2044 (2695.73 mm/year) followed by 2053 (2693.09 mm/year), 2052 (2687.69 mm/year), 2065 (2656.17 mm/year), 2051 (2647.21 mm/year) and 2061 (2635.31 mm/year). The lowest mean annual PET is expected to be in the year 2048 (2271.71 mm/year) followed by 2025(2367.17.84 mm/year). This is due to temperature variations over the years.

Mann-Kendall test parameters namely Kendall's tau, S-statistic and p-value of mean annual PET were 0.045, 55 and 0.651 respectively at 95% confidence level. The positive value of Kendall tau and S-statistic depicted the increasing trend in PET for the time series of 50 years (2021-2070) over India. The p-value is greater than significance level alpha (0.05), which indicates positive but non-significant trend over India. The estimated Sen's slope for time series data is 0.316 at 5% level of significance. This showed that there is a positive slope in the trend and mean annual PET is increasing 0.316 mm per year. There is a slight increase in PET expected over next 50 years due to the influence of increasing mean air temperature and short wave incoming solar radiation. However, further study is required to analyse how other weather parameters viz., rainfall amount, wet and dry spells, influence on the PET, which help in planning agricultural water management projects for the coming decades.

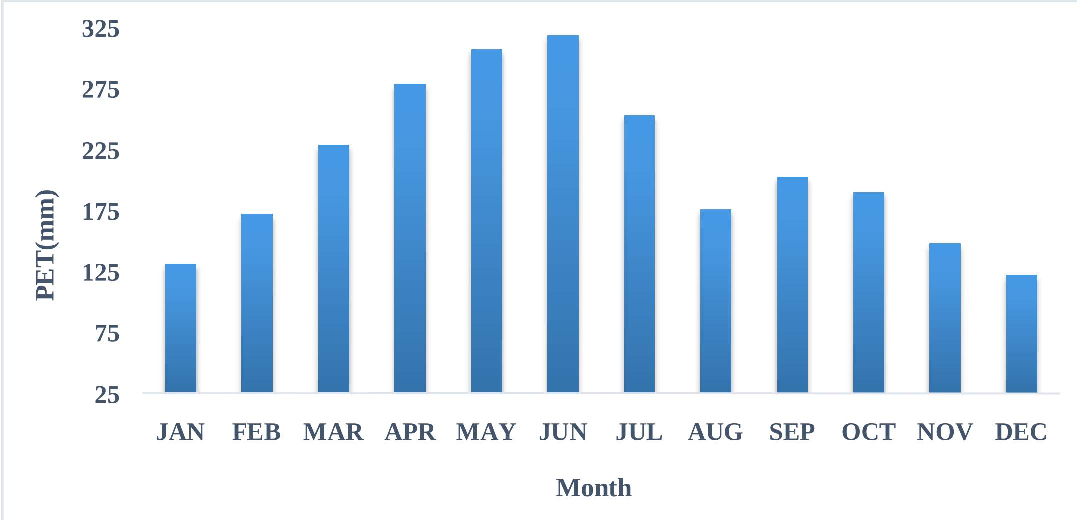

Fig. 2: Variation in mean monthly PET over India for the period 2021-2070.

Variations in mean monthly PET over India are shown in Figure 2. Mean monthly PET values for India varied from the lowest of 122.62 mm/month in December to the maximum of 319.36 mm/month in June. The highest PET is observed in the month of June (319.36 mm/month), and is followed by May (307.46 mm/month) and April (279.30 mm/month). It is seen that mean monthly PET values, show a steady rising tendency between January and June. The values show a steady falling tendency after June between July and August. Despite a slight rise in September month, a further gradual decrease in PET values is observed between September and December.

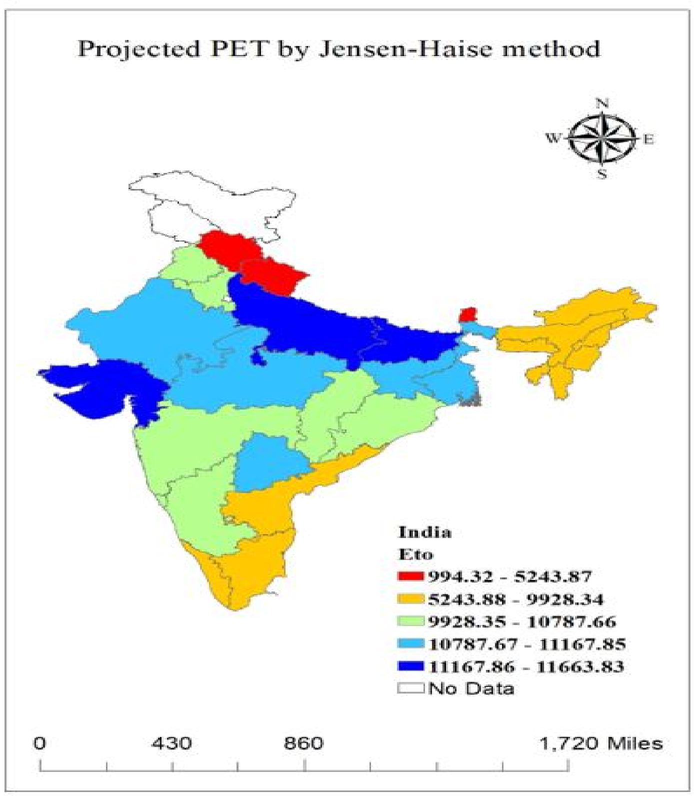

Fig. 3. Spatial variation in mean annual PET across India for the projected 50 years (2021-2070)

Variation in mean PET across different states of India is shown in figure 3. States like Gujarat (11663.83 mm), Bihar (11564.50 mm) and Uttar Pradesh (11465.57 mm) showed the highest annual average PET. In the regions where the rate of moisture loss through evapotranspiration exceeds the amount of precipitation, these states have relatively higher temperature and lower relative humidity, hence they have high mean PET. Choice of crop cultivars and cropping systems need to be tailored to the expected PET rates. Similarly, water resources management strategies need to be reassessed to meet the demands for coming decades across these states. The state of Sikkim (994.32 mm), Uttarkhand (2200.42 mm) and Himachal Pradesh (5243.87 mm) showed the lowest mean annual PET due to relatively lower temperatures and very high relative humidity.

3.2. Variations and trends in mean annual PET over Karnataka for the period 2021-2070

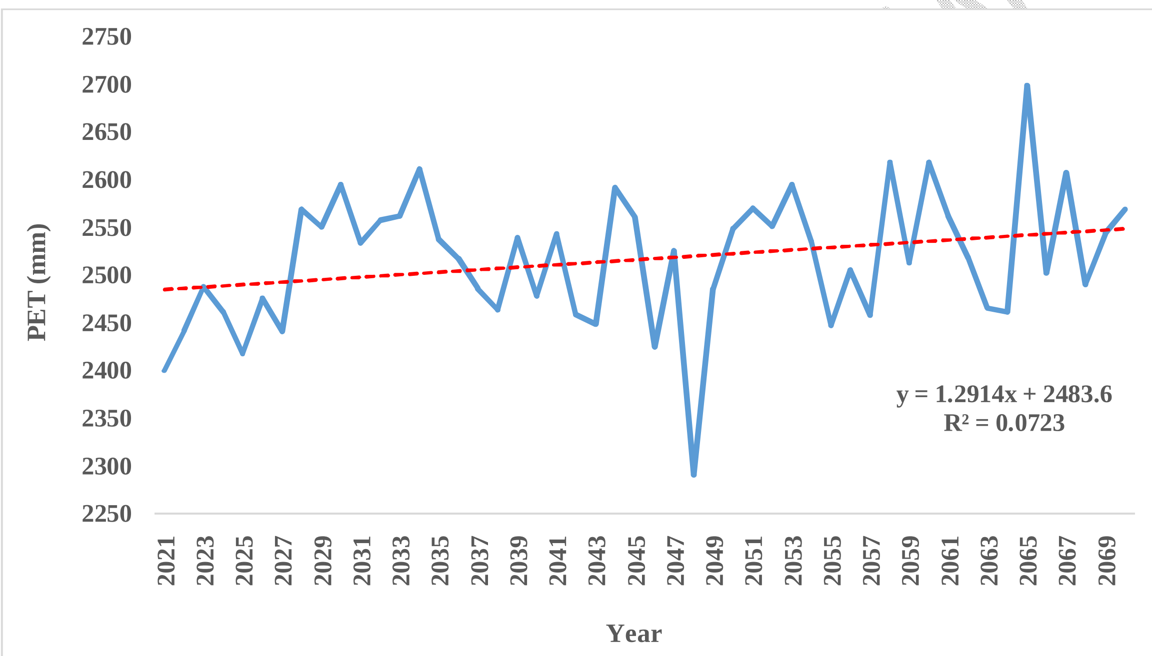

Fig. 4. Trend in mean annual PET for Karnataka state

Annual PET estimated by Jensen-Haise method over Karnataka is shown in the figure 4. The annual average PET of Karnataka is 2516 mm/year and is expected to increase during the next 50 years' period. However, when looked at annual PET values, both increasing and decreasing trends and large variations are expected with an overall increasing trend for the whole study period. A higher PET is expected in the years 2065 (2698.47 mm/year) followed by 2058 (2618.13 mm/year), 2060 (2617.93 mm/year), 2034 (2611.18 mm/year) and 2067 (2607.34 mm/year) whereas the lowest PET is expected to be in the year 2048 with 2290.30 mm/year. This higher PET could be due to exceptionally high temperatures and possibly lower relative humidity, both of which increase the rate of evapotranspiration. Increased solar radiation and possibly reduced cloud cover might also contribute to higher PET in these year. As higher temperatures and increased solar radiation are strongly correlated with higher PET values (IPCC reports 2023 and studies on climate change impacts).

Trend analysis of coming 50 years period for Karnataka was also done by using Mann-Kendall test. Mann-Kendall test parameters namely Kendall's tau, S-statistic and p-value of mean annual PET were 0.177,217 and 0.071, respectively, at

95% confidence level. The positive value of Kendall tau and S-statistic depicted the increasing trend in the PET over next 50 years (2021-2070). The p-value was found to be greater than significance level alpha (0.05), hence there is positive but non-significant trend in PET for Karnataka. The estimated Sen's slope for time series data was 1.049 at 5% level of significance. This showed that there is a positive slope in the trend and mean annual PET is increasing 1.049 mm per year. There is a slight increase in PET observed over years due to influence of variation in mean air temperature and relative humidity. However, further study is required to analyse how other weather parameters, along with air temperature and relative humidity influence on the PET.

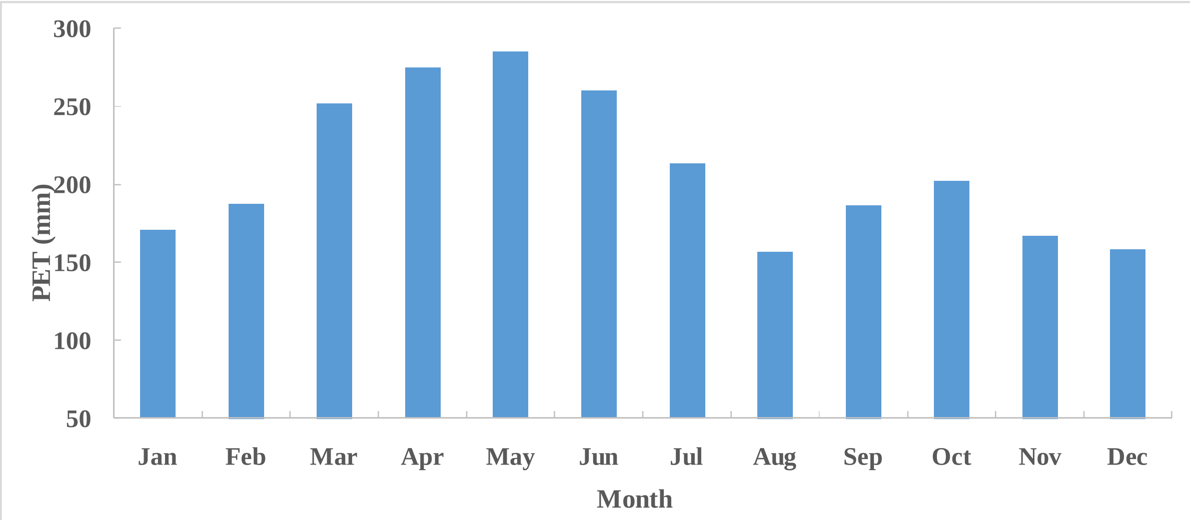

Fig. 5. Variation in mean monthly PET over Karnataka for the period 2021-2070.

The mean monthly PET values for Karnataka were found to be the lowest in December (285 mm/month), and from the month of January to May, a steady rise in mean monthly PET values were observed. It is clearly evident in bar graph shown in figure 5 that there is a consistent rising trend between January and May, and drops after May month until end of August. After the end of August, further gradual increase in PET values is observed between September and October. The lowest mean monthly PET value was recorded for August (157 mm/year).

Table 1: State-wise annual mean PET, Mann-Kendall trend and Sen's slope over India for next 50 years (2021-2070).

Sl.No	States	Mean PET (mm/year)	Mann-Kendall test			Sen's slope
			P-value	Kendall's tau	S statistic	
1	Andhra Pradesh	2179.40	0.015	0.239	293	0.164
2	Arunachal Pradesh	1839.07	<0.0001	0.556	681	6.879
3	Assam	2272.56	0.019	0.229	281	1.943

4	Bihar	2775.47	<0.0001	0.401	491	3.225
5	Chhattisgarh	2575.86	0.120	0.153	187	0.972
6	Goa	2516.52	0.071	0.177	217	1.049
7	Gujarat	2799.31	0.066	0.180	221	1.112
8	Haryana	2589.03	<0.0001	0.461	565	2.730
9	Himachal Pradesh	1258.52	0.000	0.350	429	2.589
10	Jharkhand	2599.81	0.010	0.252	309	2.156
11	Karnataka	**2516.52**	0.071	0.177	217	1.049
12	Kerala	2371.13	0.008	0.259	317	1.815
13	Madhya Pradesh	2680.28	0.973	0.004	5	0.049
14	Maharashtra	2544.79	0.403	-0.082	-101	-0.645
15	Manipur	2187.61	<0.0001	0.595	729	8.237
16	Meghalaya	2372.69	<0.0001	0.450	551	2.853
17	Mizoram	2343.46	0.676	0.042	51	0.189
18	Nagaland	2312.47	<0.0001	0.504	617	3.761
19	Odisha	2565.02	0.026	0.218	267	1.538
20	Punjab	2514.10	0.003	0.287	351	1.828
21	Rajasthan	2606.96	0.000	0.347	425	1.815
22	Sikkim	238.63	0.000	0.375	459	3.048
23	Tamil Nadu	2371.13	0.008	0.259	317	1.815
24	Telangana	2667.60	0.046	0.195	239	1.576
25	Tripura	2285.92	<0.0001	0.409	501	2.381
26	Uttarakhand	528.10	0.001	0.314	385	2.366
27	Uttar Pradesh	**2751.73**	0.005	0.272	333	2.164
28	West Bengal	2654.95	**<0.0001**	0.381	467	2.674

4. DISCUSSION

The assessment of mean annual potential evapotranspiration (PET) across India, specifically in Karnataka for the period 2021-2070 reveals significant insights into the impacts of climatic factors on water resources. The analysis indicates a complex interplay between mean air temperature and incoming solar radiation, both of which are critical in determining PET values.

National Trends in PET

The national trend analysis shows a slight overall increase in mean annual PET over the projected 50-year period, despite periodic fluctuations. The anticipated peak PET of 2695.73 mm/year in 2044 and the lowest value of 2271.71 mm/year in 2048 underscore the variability in climatic conditions affecting evapotranspiration rates.

The Mann-Kendall test results, with a Kendall's tau of 0.045 and a p-value of 0.651, indicate a positive but non-significant trend. This suggests that while an upward trend in PET can be expected, its statistical significance remains questionable, highlighting the necessity for further investigation into the factors influencing these trends.

The estimated Sen's slope of 0.316 mm/year reflects a gradual increase in PET, which is likely driven by rising mean air temperatures and changes in solar radiation patterns. The observed fluctuations may be attributed to interannual climate variability, including potential influences from phenomena such as El Niño or the Indian monsoon's variability.

Monthly Variations

Monthly PET values exhibit a clear seasonal pattern, with a peak in June (319.36 mm/month) and a notable decrease through the remainder of the year. This trend is significant for agricultural practices, as it indicates the months of highest evapotranspiration coincide with the Indian summer, which typically has lower soil moisture availability. Understanding these seasonal dynamics is crucial for optimizing irrigation strategies and managing water resources, especially during the critical growing seasons.

Spatial Variation Across States

The spatial analysis reveals substantial disparities in mean annual PET across different states. States like Gujarat, Bihar, and Uttar Pradesh, with mean PET values exceeding 11,000 mm/year, experience higher temperatures and lower relative humidity, leading to increased evapotranspiration. Conversely, states like Sikkim, Uttarakhand, and Himachal Pradesh show much lower PET values, attributed to their cooler climates and higher humidity levels. These findings suggest that agricultural policies and practices should be region-specific, addressing local climatic conditions and the unique challenges posed by varying PET rates.

Karnataka's Specific Trends

In Karnataka, the mean annual PET is projected to increase from an average of 2516 mm/year, with the highest values expected in 2065 (2698.47 mm/year) and a notable low in 2048 (2290.30 mm/year). The Mann-Kendall test results indicate a positive trend (Kendall's tau = 0.177, p-value = 0.071), though non-significant, reinforcing the necessity for adaptive management strategies in response to potential changes in PET.

The rising PET in Karnataka can be linked to expected increases in temperature and variations in solar radiation, potentially exacerbated by changes in land use and land cover, which may affect local microclimates. The Sen's slope of 1.049 mm/year indicates a relatively higher increase in PET compared to the national average, suggesting that Karnataka may face unique challenges related to water availability and agricultural productivity in the coming decades.

Implications for Agricultural Practices

The anticipated rise in PET necessitates a re-evaluation of agricultural practices, particularly in water-scarce regions. Crop selection, irrigation practices, and water resource management strategies must be adapted to accommodate these changes. In states with high PET, such as Gujarat and Bihar, the focus may need to shift towards drought-resistant crop varieties and improved irrigation efficiency.

Conversely, regions with lower PET may require strategies to manage excess moisture and optimize water use efficiency.

CONCLUSION

This study aimed to study and analyse the annual and monthly trends of PET over India, different states and particularly Karnataka for the projected period from 2021 to2070. Observational data for the India as a whole showed an increasing trend in PET, because of the fact that global average temperature is expected to rise over the next 50 years. This means that PET trends are influenced mainly by temperature and followed by others factors such as solar radiation, relative humidity, wind speed, and so on. Looking at the PET trends reveals that two major potential causes of PET change is mean air temperature and solar radiation, and are changing over the next 50 years. The magnitude of change and importance of each of the causes varies by location, so the PET trend varies by region, though there is an overall positive trend. The statistically significant increase in both rainfall amount and PET suggestedthat the differences in the rate of increase of these two hydrologicalcomponents would determine the climatic water balance scenario in the future (Ashaolu and Iroye, 2018).Any changes in evapotranspiration is likely to have a significant impact on crop water demand, choice of crops and cropping systems, agriculture productivity and water resources availability . The current study offers a preliminary idea about the likely change in PET for India, states and specifically for Karnataka. Although the study's findings are estimates, they may be useful in the future for planning, designing, and operating irrigation systems and accordingly working on crop planning. Our water management strategies for the coming decades must account for these expected variations in order to avoid moisture stress or drought like occurrences and achieve higher crop yields under less water usage.

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 the writing or editing of this manuscript.

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