ASSESSING THE EVAPOTRANSPIRATION OVER DIFFERENT STATES OF NORTH-EAST INDIA USING SATELLITE BASED DATA

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Abstract: Evapotranspiration (ET) plays a crucial role in the hydrological cycle and shifts in its pattern can directly influence the availability and distribution of water resources within the concerned region. The contribution of ET varies from place to place, reflecting land cover heterogeneity. As such, the present study analyses climate change and its effects on the hydrological cycle through investigating the variation of water budget-derived ET in different states of North-East India (NEI). The MODIS satellite retrieved ET dynamics exhibits an increasing trend at a rate of 3.28 mm/year over NEI during 2000-2021. The highest ET (>1000 mm/year) is observed in the states with more forest cover: Manipur, Mizoram, Nagaland and Tripura while, Arunachal Pradesh exhibits the lowest ET (698 - 812 mm/year) because some of its mountains are covered with snow and owing to its latitudinal positions. Trend analysis exhibits a significant rise in annual ET across Assam (4.26 mm/year), Manipur (3.58 mm/year), Meghalaya (3.71 mm/year), Mizoram (5.36 mm/year), Nagaland (3.58 mm/year) while in Arunachal (1.37 mm/year) and Tripura (5.06 mm/year) the observed trends are insignificant, which are evaluated by Mann-Kendall Test. The analysis reveals that the highest ET occurs in monsoon season in all the states and lowest in the winter season. Most of deciduous plants reached its maximal growth during high ET season that coincided with highest amount of rainfall and sufficient soil moisture. This study highlights the importance of considering vegetation and geographical position in analyzing ET.

Keywords: Evapotranspiration, North-East India, MODIS satellite, Mann-Kendall test.

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1 Introduction

Evapotranspiration is the process through which water is transferred from land to the atmosphere, combining evaporation from water bodies and soil surface along with transpiration from plants [1, 2]. It is a key component of the hydrological cycle, influencing agricultural productivity, soil moisture availability, drought occurrence and regional hydrological balance. The major meteorological parameters influencing ET are temperature, precipitation, solar radiation, relative humidity, wind speed, soil moisture *etc.* [3–6]. Topography and elevation are also two key factors which strongly affect the regional conditions of the study domain. Seasonal and inter-annual variation of ET are key regulating factors of terrestrial hydrological processes, vegetation dynamics, surface energy fluxes, climate variability and regional water balance. Therefore, ET responds differently to climatic variables in different places under different climatic conditions. So, accurate estimation of ET in different places is critical for forecasting actual crop evapotranspiration, irrigation scheduling, water management, climate modelling, and other practices of agricultural productivity and prediction of extreme events like drought [7, 8]. As such, this study focuses on investigating the trends of evapotranspiration in different states of North- East India (NEI).

However, the network of ground-based ET observations is limited, discontinuous and difficult to scale up, particularly in areas like NEI, which is a topographically complex region. In the absence of long-term ground-based

ET observations in NEI, satellite-based products provide the only consistent source of regional ET information. While these datasets are subject to uncertainties arising from cloud cover, complex terrain and heterogeneous land cover, they nevertheless provide valuable spatially continuous estimates. Satellite-based remote sensing has emerged as a powerful approach for monitoring ET across large spatial and temporal scales. These products integrate multi-sensor observations of radiation, temperature, vegetation indices and soil moisture with land surface models to provide spatially continuous ET values. Such data are especially valuable in regions with limited ground measurements, enabling inter-comparison and trend analysis across complex terrain.

Several global studies have utilised MODIS, GLEAM, ERA5-Land products to assess spatial patterns, seasonal variability and trends in ET for different river basins and agro-climatic zones [9–13]. Some Indian researchers have found that ET trends vary regionally due to monsoon variability, land-use change, irrigation and vegetation dynamics and with high uncertainties where ground observations are sparse. ET estimation and validation in NEI is challenging due to sharp elevation gradients, dense forest cover, highly variable monsoonal precipitation and limited ground-based observation station. Jhajharia et al. observed the reference evapotranspiration is decreased in humid region of NEI due to net radiation and wind speed [14]. This motivates the present study to perform a systematic, state-wise ET assessment for NEI, quantifying seasonal variation in different states using satellite-based data products. Such analysis is essential for assessing regional water balance, agricultural water use and climate change impacts.

2 Study area

The study focuses on the NEI region, which comprises eight states: Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim. Geographically, the region is located at the easternmost part of India, spans an area of approximately 2,62,179 square kilometres, accounting for 7.97% of the country's total geographical area [15]. NEI region is predominantly hilly and mountainous, except for the Brahmaputra and Barak River valleys in Assam and low-lying plains of Tripura. The region comprises of some of the wettest places on Earth, such as Cherrapunji and Mawsynram in Meghalaya. They receive more than 10,000 mm rainfall annually [16]. Climatologically, the region experiences four distinct seasons: pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February) season with abundant rainfall of 1500-6000 mm during monsoon season. The region is characterized by dense vegetation, rich biodiversity and variety of land cover types - from evergreen forests and grasslands to agricultural croplands and wetlands. Altitude variation, vegetation and climatic patterns making NEI an ecologically sensitive and hydrologically complex region.

3 Data and Methods

3.1 Data description

ET data are provided by various satellite based and reanalysis datasets, which serves as an alternative in areas where in-situ observations are limited. NEI region has only a few numbers of monitoring stations. This limited data of ET does not accurately reflect the overall scenario of the region. In the present study, ET product over the study domain is obtained from the time-series MODIS 8-day products (MOD16A2) with spatial resolution of 500m during 2000-2021 (`https://modis.gsfc.nasa.gov/data/`). This data product has been extensively validated and widely used across the globe [17, 18].

MOD16 algorithm is based on the Penman-Monteith equation which integrates meteorological inputs and vegetation information derived from MODIS. We adopted the approach proposed by [19],

$$\lambda E = \frac{sA' + \rho C_p \frac{e_{\mathrm{sat}}-e}{r_a}}{s + \gamma\left(1 + \frac{r_s}{r_a}\right)} = \frac{sA' + \rho C_p \frac{\mathrm{VPD}}{r_a}}{s + \gamma\left(1 + \frac{r_s}{r_a}\right)}. \tag{1}$$

where, s denotes the slope of the curve describing the relationship between saturated vapor pressure (e_{sat}) and temperature, mathematically expressed as $\frac{d(e_{sat})}{dT}$; VPD is calculated as $e_{sat} - e$, where e is the actual air vapor pressure, λE refers to the latent heat flux, A' indicates the amount of available energy on land surface, ρ is air density and C_p represents the specific heat capacity of air. Here, r_a and r_s refers aerodynamic resistance and surface resistance respectively which are the key factors for evaporation.

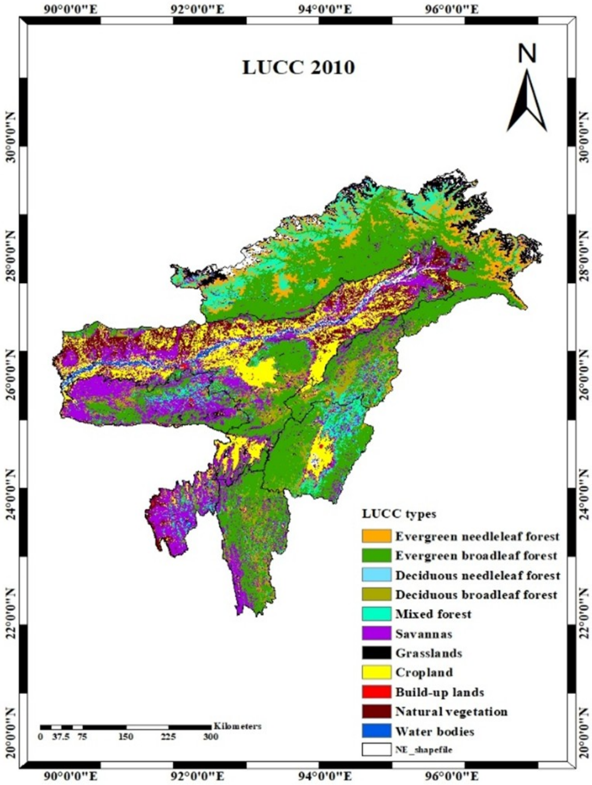


Figure 1: Land Use and Land Cover map of NEI for the year 2010.

3.2 Methodology

A non-parametric Mann-Kendall (MK) test was employed to identify the presence and extent of trends in ET over different states of NEI. This test is widely used in hydro-climatic studies since it does not rely on normally distributed data and is relatively less sensitive to missing values or outliers. It evaluates whether the data exhibit a monotonic increasing or decreasing trend over time. The test statistic (S) is computed as follows,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i) \tag{2}$$

Here, n represents the total number of observations, x and x denote the data values in time series i and $j(j > i)$, respectively.

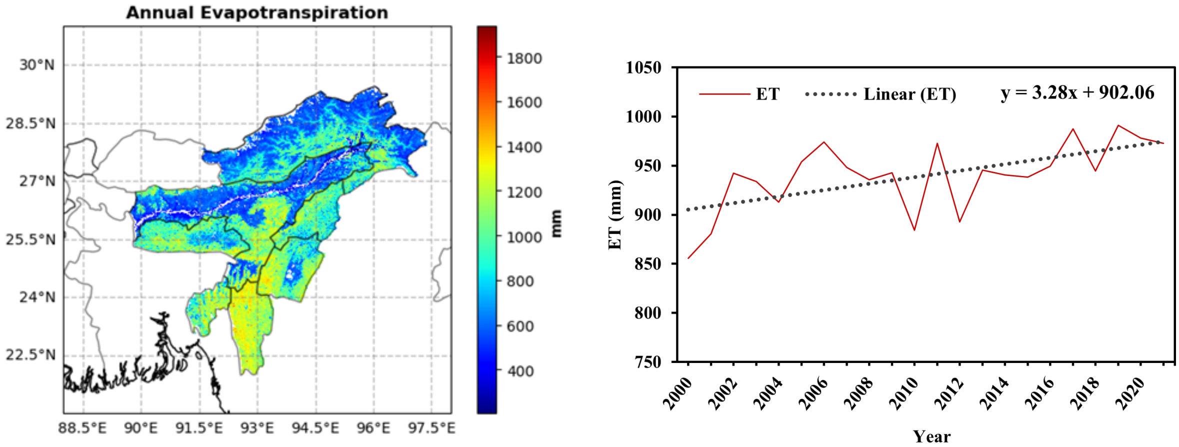
$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{Var}(S)}}, & \text{when } S > 0, \\ 0, & \text{when } S = 0, \\ \dfrac{S+1}{\sqrt{\mathrm{Var}(S)}}, & \text{when } S < 0. \end{cases} \tag{3}$$

Then standardized test statistic (Z) is used to assess the significance of the trend at 99% and 95% confidence levels. Additionally, the Sen's slope estimator is applied to quantify the magnitude of the identified trends. In this study, trend analysis was performed for seasonal and inter-annual ET time series data obtained from MODIS satellite for each state.

4 Results and Discussion

The interannual variation of ET with values fluctuating approximately 850-1000 mm during 2000-2021 (Fig. 2b and a consistent positive trend at a rate of 3.28 mm/year was observed, indicating a gradual rise in ET over the past two decades. This increasing trend likely reflects the combined influence of rising temperatures, enhanced atmospheric water demand, and potential changes in vegetation productivity in response to a warming climate.

Fig. 2a reveals pronounced spatial heterogeneity of ET value over the region. High ET values >1000 mm/year are observed in Mizoram, lower plains of Assam, Manipur, Nagaland and Tripura. In contrast, Arunachal Pradesh exhibited the lowest ET despite having dense forest cover, which is attributed to its higher latitudinal position. Higher latitude places receive less solar radiation. Because latitude controls angle and duration of solar radiation over a region.



(a) (b)

Figure 2: Spatial and temporal distribution of evapotranspiration over NEI during 2000-2021 using MODIS data.

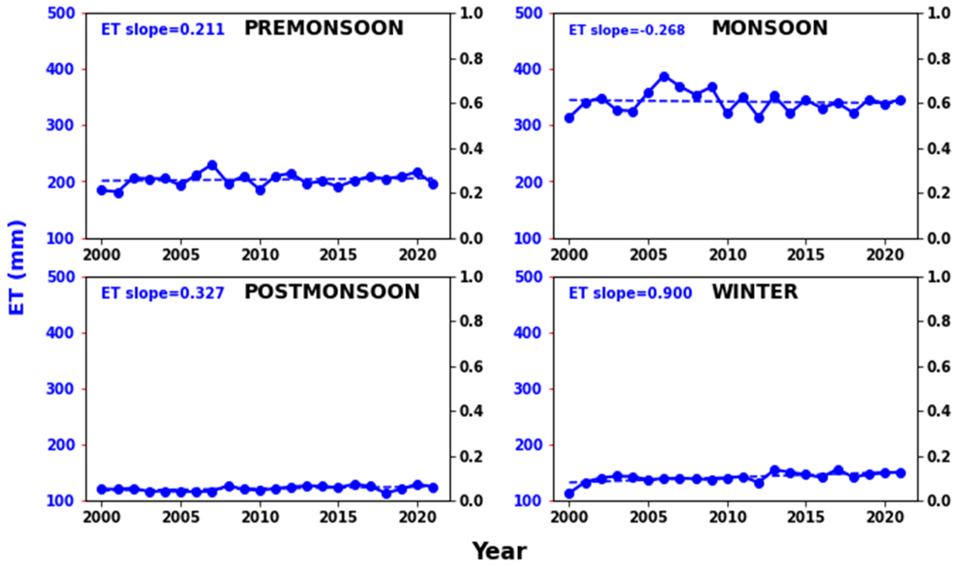
The seasonal analysis of ET over different states of NEI exhibit distinct seasonal pattern. In Arunachal Pradesh, ET values generally ranged between 180-230 mm and showed a slight increasing tendency at a rate of 0.211 mm/year during the pre-monsoon season (Fig. 3a). In contrast, monsoon season exhibited the highest seasonal ET magnitudes (∼300-400 mm), reflecting the strong influence of peak rainfall and vegetation activity with a decreasing trend at a rate of -0.268 mm/year. This could be associated with cloud induced reduction in net solar radiation or changes in vegetation dynamics during peak monsoon months. The post-monsoon season displayed a weak but positive trend (0.327 mm/year). Similarly, the winter season showed the lowest ET values (∼100-130 mm) but exhibited the strongest increasing trend (0.90 mm/year).

A consistent increase in ET across all seasons in Assam with rates of 0.573 mm/year in pre-monsoon, 1.565 mm/year in monsoon, 0.901 mm/year in post-monsoon and 0.913 mm/year in winter (Fig. 3b). The most pronounced changes during the monsoon, likely driven by increasing temperature, enhanced radiation and vegetation dynamics in response to changing climate conditions. Similarly, Tripura also showing increasing trend for all the seasons (Fig. 3c).

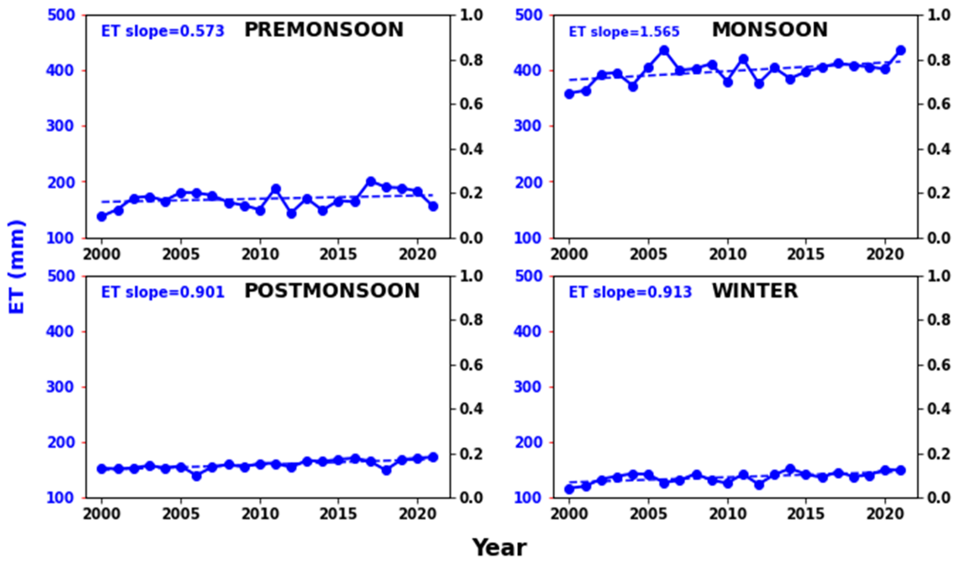
In Manipur, ET ranged between 200-400 mm and showed a notable increasing trend (1.304 mm/year), indicating enhanced land surface heating and vegetation activity before the onset of monsoon rains. The monsoon season exhibited the highest ET positive trend (0.802 mm/year). The winter season recorded comparatively lower ET (∼200-250 mm) but showed a clear increasing trend (0.911 mm/year) (Fig. 3d).

In Nagaland, although monsoon contributes most to the total ET, its trend is slightly declining which is similar to Arunachal Pradesh, while non-monsoon seasons show increasing ET, especially winter and pre-monsoon, suggesting seasonal shifts and intensification of ET (Fig. 3e). In Mizoram, the highest annual increment of ET was noticed (2.69 mm/year) during pre-monsoon followed by monsoon (2.06 mm/year) (Fig. 3f). In Meghalaya, ET is highest during the monsoon season (400-550 mm), followed by the pre-monsoon (∼200-300 mm), post-monsoon (∼200-250 mm) and winter (∼150-200 mm) seasons and all four seasons show positive trends (Fig. 3g).

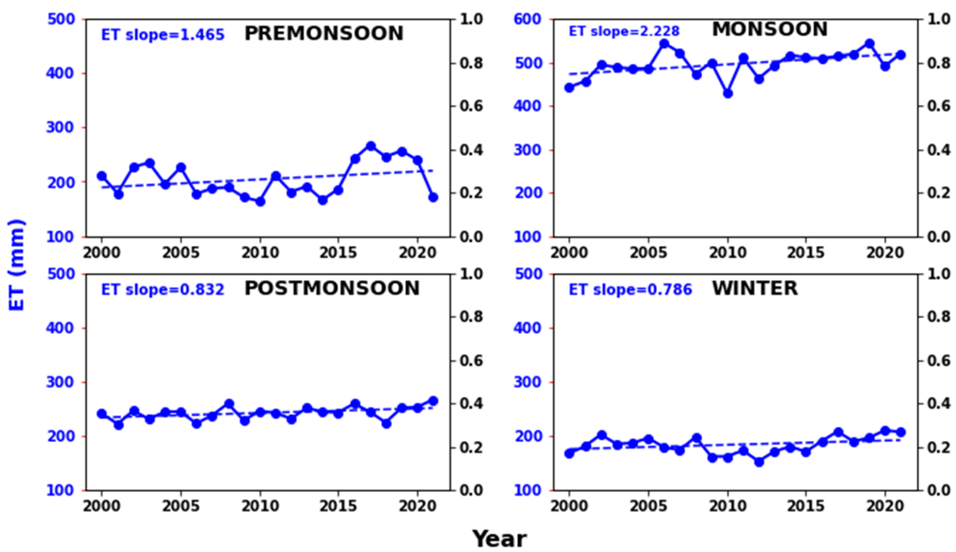
A comparative analysis of NEI states reveals that Tripura exhibits the highest increasing trend in monsoon ET (2.228 mm/year) followed by Mizoram (2.06 mm/year) and Assam (1.565 mm/year), while Arunachal Pradesh and Nagaland exhibit declining trends of -0.268 mm/year and -0.005 mm/year respectively.



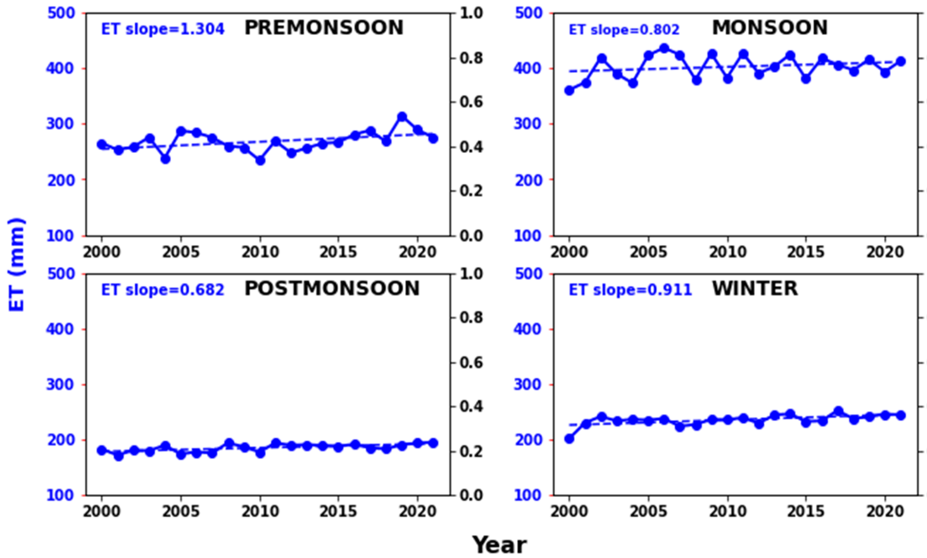
(a) Arunachal Pradesh



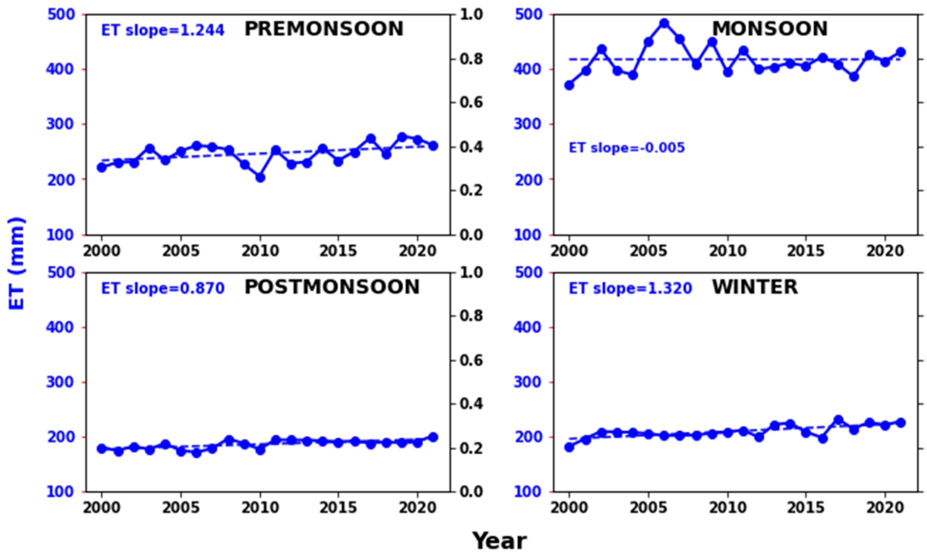
(b) Assam



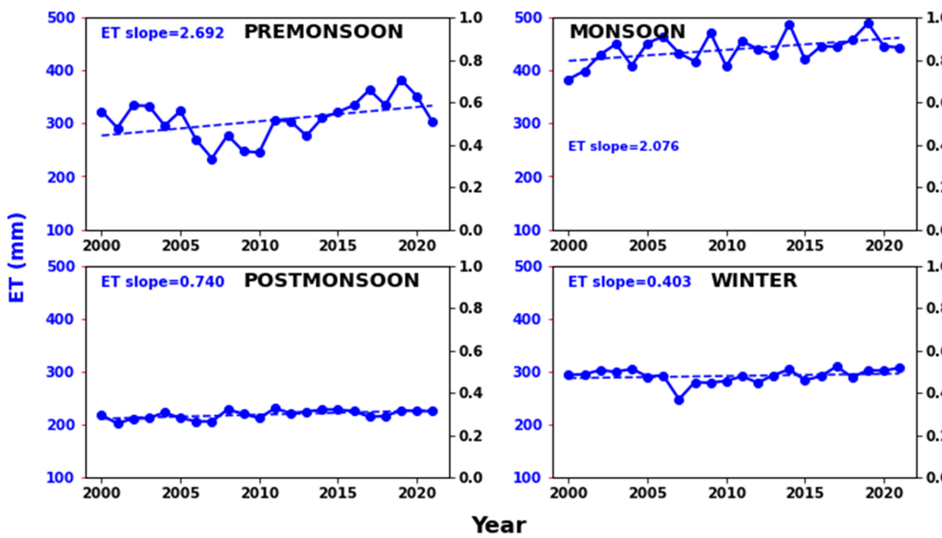
(c) Tripura



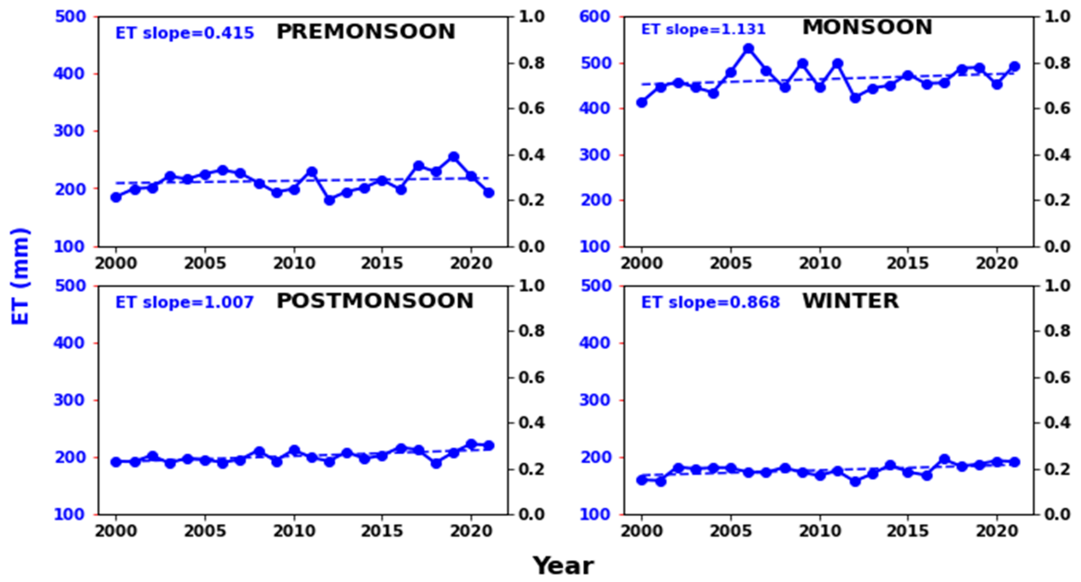
(d) Manipur



(e) Nagaland



(f) Mizoram



(g) Meghalaya

Figure 3: Temporal changes of ET during 2000-2021 over different states of NEI (a) Arunachal Pradesh (b) Assam (c) Tripura (d) Manipur (e) Nagaland (f) Mizoram (g) Meghalaya.

5 Conclusion

The present study indicates a significant increasing trend in ET across NEI during 2000-2021, highlighting its important role in the regional hydrological cycle in a changing climatic condition. The scarcity of reliable ground-based ET measurements in NEI, the present study provides an overview of ET behavior using the best-available satellite-derived products. The spatial pattern of ET is influenced by differences in land cover types, with the highest ET values observed over vegetation dominated states such as Mizoram, Manipur, Tripura and Nagaland, and the lowest over Arunachal Pradesh due to its higher latitudinal position. Seasonally, ET shows the highest value during monsoon in association with maximum rainfall and vegetation growth, and the minimum value in winter due to dry conditions, leaf fall and limited crop growth. Most of the states exhibit increasing ET trends, while negative trends in the monsoon season over Arunachal Pradesh and Nagaland indicate the influence of altered rainfall patterns on vegetation water use. These findings emphasize that ET is undergoing gradual intensification and seasonal redistribution of ET, impacting water availability, ecosystem productivity, and climate resilience planning in the region. The analysis establishes a much-needed baseline of spatial and temporal ET variability over this complex and data-limited region. This baseline assessment can guide future efforts incorporating high-resolution reanalysis datasets, improved downscaling techniques and dedicated field observations to better quantify and validate ET processes in NEI.

Data availability:

MODIS data can be accessed through (`https://modis.gsfc.nasa.gov/data/`) website.

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