Evapotranspiration in a Changing Climate: A Multi-Parameter Analysis of Recent Trends and Seasonal Variations

Mrs. Hasanapuram Sushmitha

YOGI VEMANA UNIVERSITY

Vemanapuram, Kadapa-516005, Andhra Pradesh, India

Supervision of Prof.K.Krishna Reddy

Email: Sushmithahsr29@gmail.com

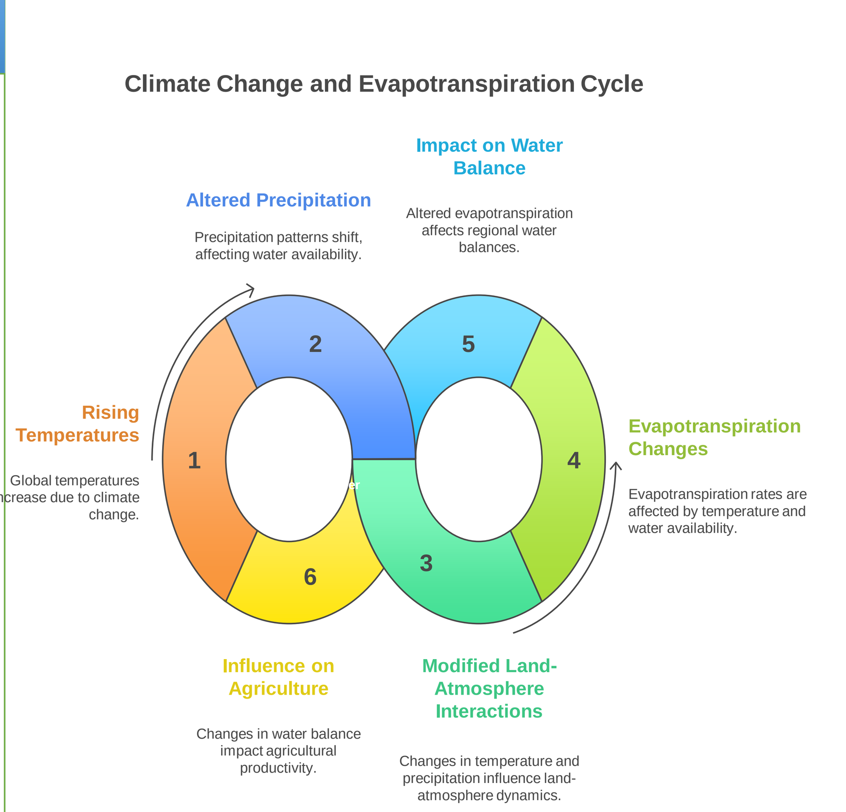
WCRP World Climate Research Programme · CLIVAR · 30th Anniversary

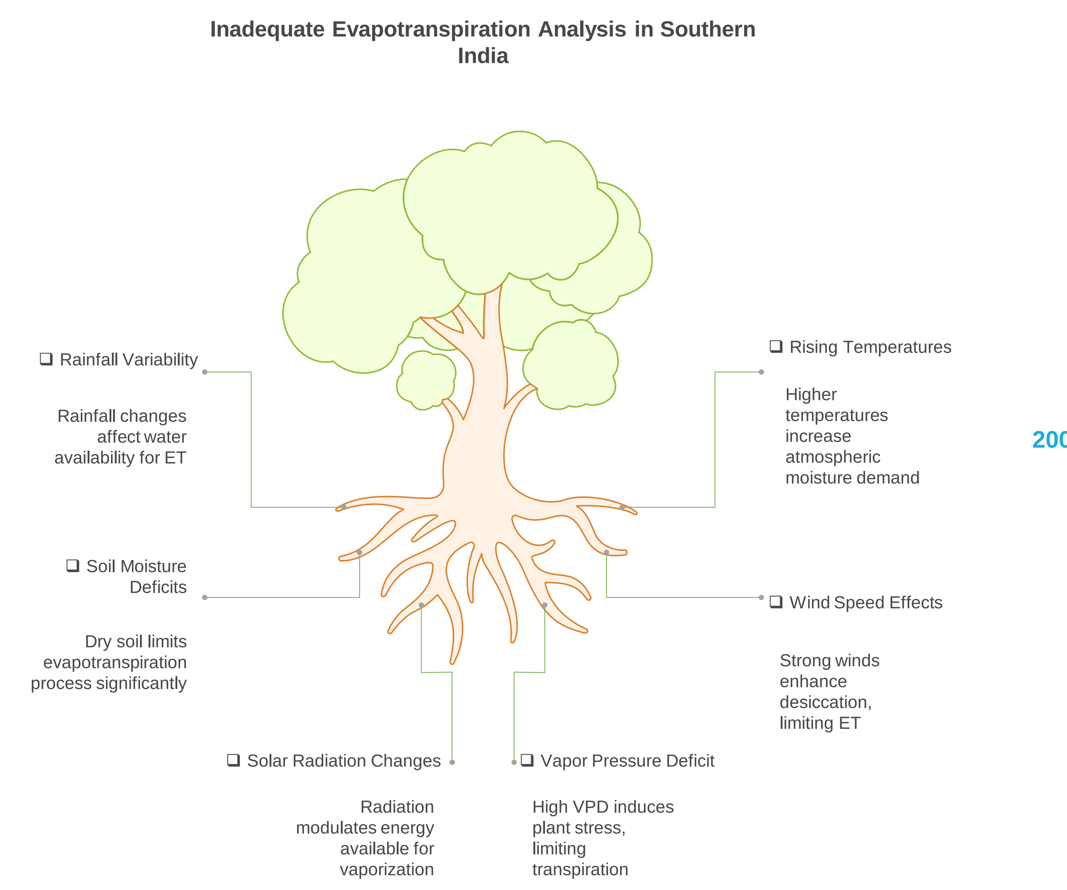
Abstract

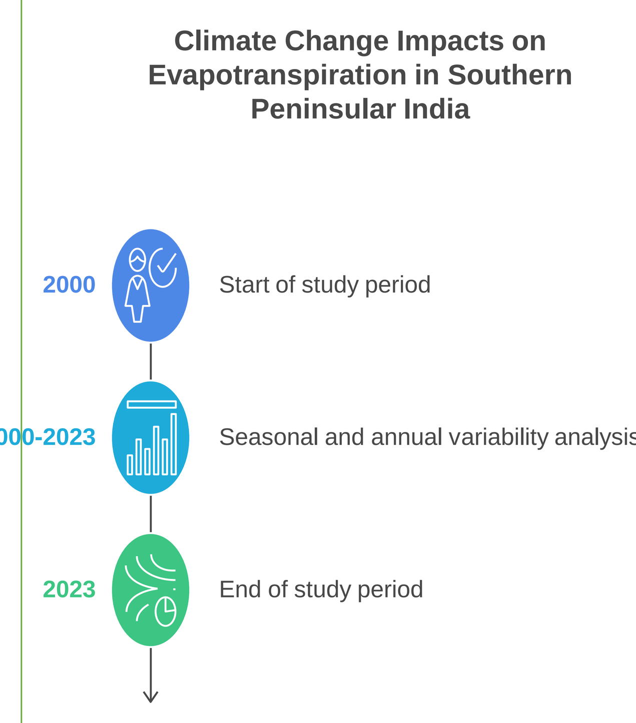
Evapotranspiration (ET) is a vital component of the hydrological cycle, highly sensitive to climatic variability and atmospheric demand. This study investigates the long-term trends in actual ET and its relationship with key meteorological parameters across Southern Peninsular India during the period 2000–2023. ET data from the GLDAS model was analysed+ alongside air temperature, precipitation, wind speed, solar radiation, and vapor pressure deficit (VPD) sourced from ERA5 and IMD datasets. The Mann-Kendall trend test and Sen's slope estimator were applied to detect trends, while Pearson correlation analysis was used to assess the association between ET and meteorological drivers. The results indicate a statistically significant increasing trend in ET across large parts of the region, particularly during the pre-monsoon and post-monsoon seasons. Air temperature and VPD showed strong positive correlations with ET ($r > 0.6$), highlighting the increasing atmospheric demand as a dominant driver. Precipitation trends were spatially inconsistent, with notable declines in some districts, suggesting that ET rise is increasingly driven by evaporative demand rather than moisture supply. Wind speed exhibited a declining trend over the study period, potentially offsetting ET increases in some zones. Solar radiation showed minor interannual variability but contributed to seasonal ET dynamics. These findings suggest a growing divergence between ET and precipitation patterns, with important implications for water balance, crop water requirements, and drought preparedness in Southern Peninsular India. The study underscores the need to integrate evolving ET trends into regional water management and climate adaptation strategies to ensure sustainable agricultural and hydrological planning under changing climatic conditions.

Keywords

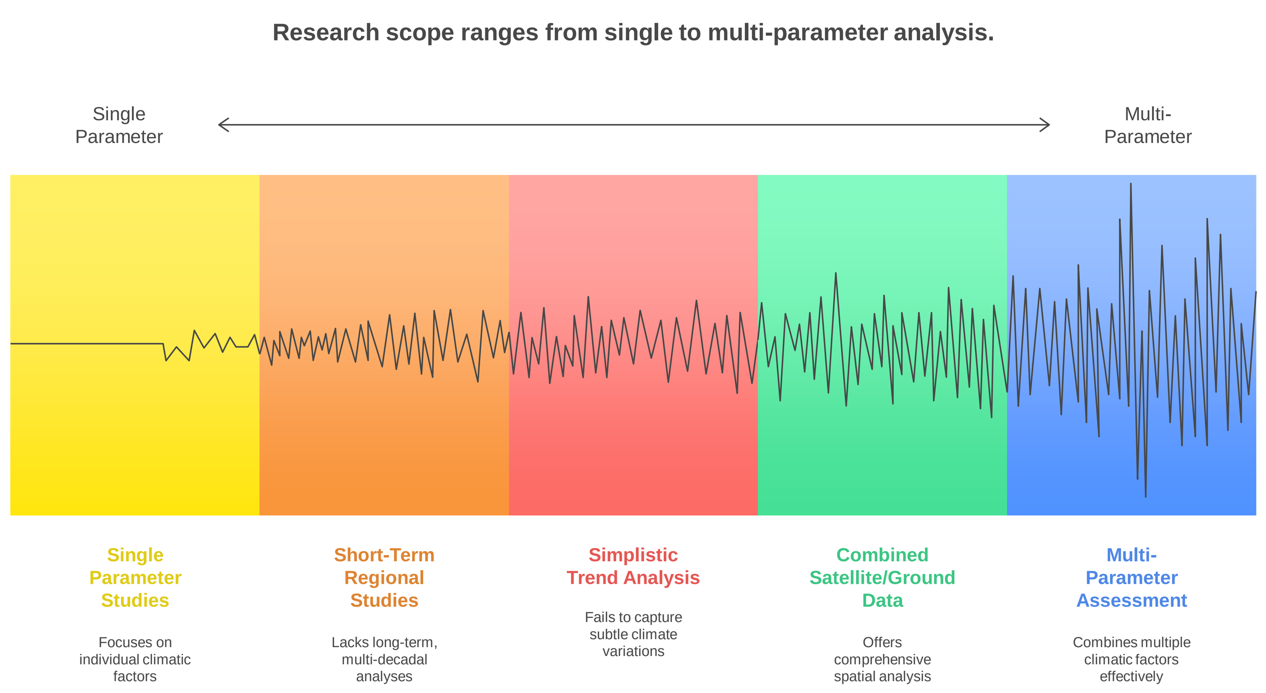
Evapotranspiration, Trend Analysis, Vapor Pressure Deficit, Climate Change, Southern Peninsular India, GLDAS, ERA5, Meteorological Parameters.

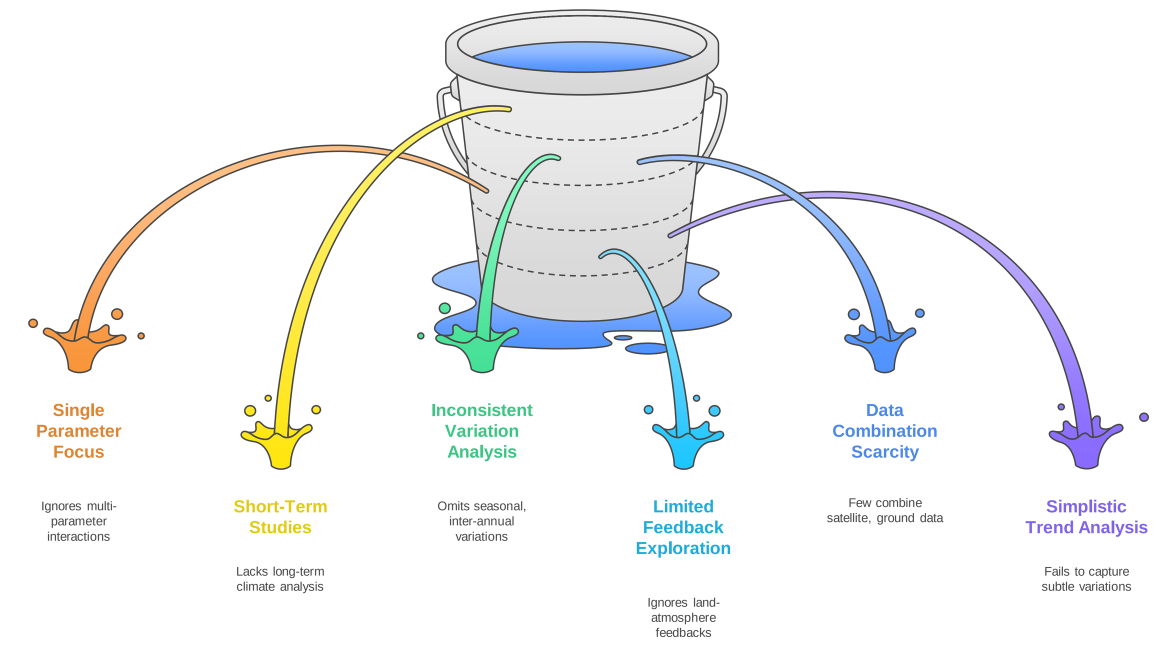




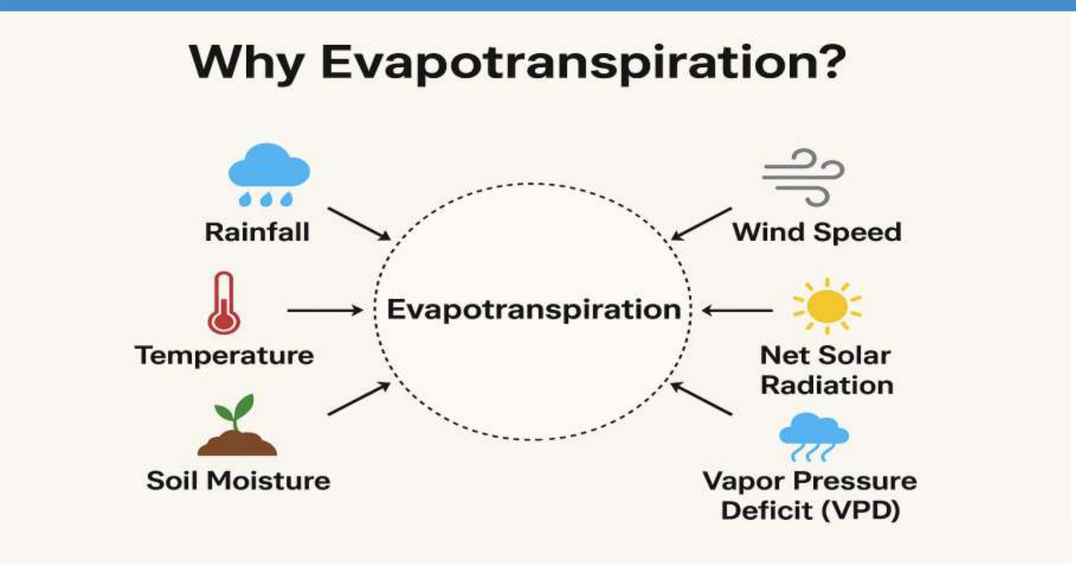


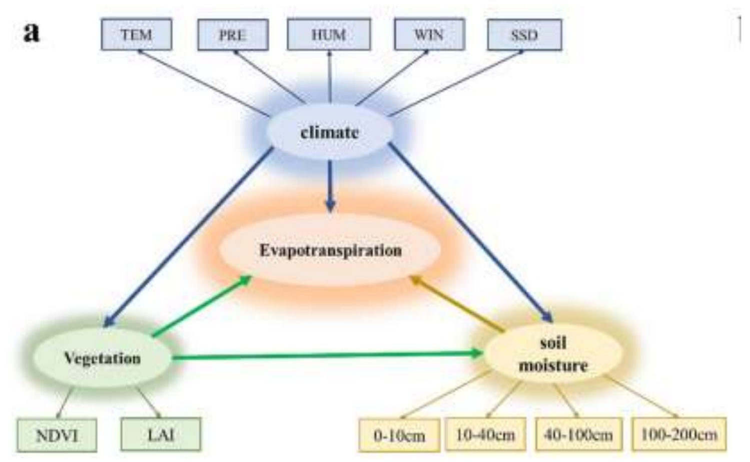
Research Gap

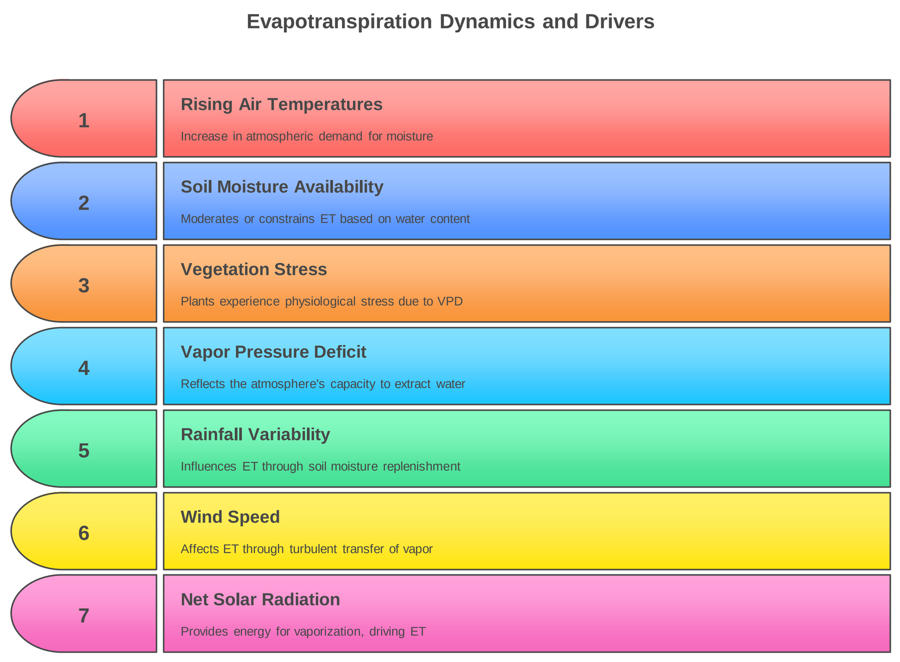


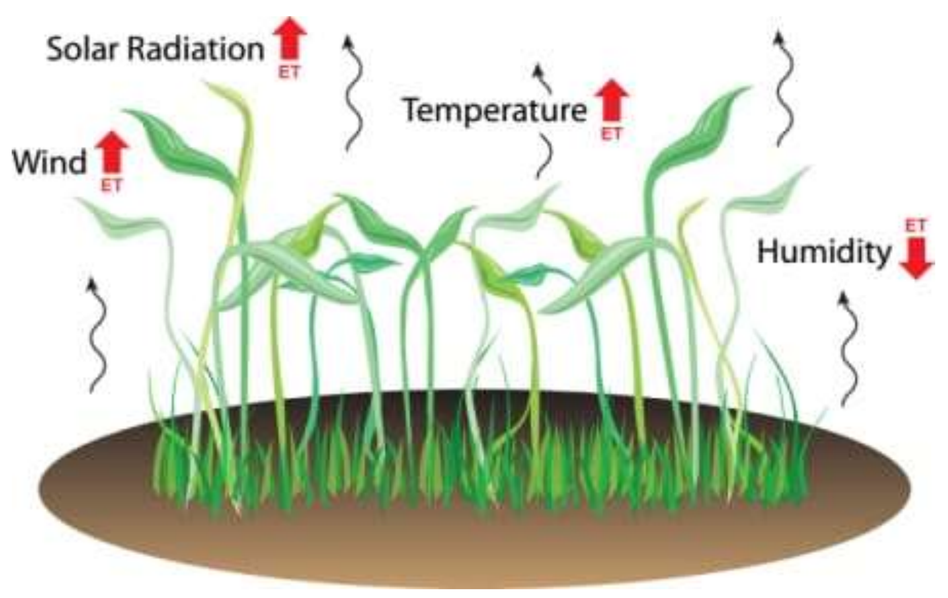


Introduction









Data

S.No	Variable	Units	Source	Data link	Temp.Res.	Spat.Res.	Period of study	End Date
1	Evapotranspiration	mm/day	GLDAS Model	https://giovanni.gsfc.nasa.gov/giovanni/ https://disc.gsfc.nasa.gov/datacollection/GLDAS_NOAH025_M_V2.1.html	Monthly	0.25 °	2000-2023	2023-12-31
2	Temperature	Kelvin	ERA 5	https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels-monthly-means?tab=download	Monthly	0.25 °	2000-2023	2023-12-31
3	Rainfall	mm	IMD	https://imdpune.gov.in/cmpg/Griddata/Rainfall_25_NetCDF.html	Monthly	0.1 °	2000-2023	2023-12-31
4	Soil Moisture	m^3/m^3	GLDAS Model	https://giovanni.gsfc.nasa.gov/giovanni/ https://disc.gsfc.nasa.gov/datacollection/GLDAS_NOAH025_M_V2.1.html	Monthly	0.25 °	2000-2023	2023-12-31
5	Wind Speed	m/sec	ERA 5	https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels-monthly-means?tab=download	Monthly	0.25 °	2000-2023	2023-12-31
6	Vapor Pressure Deficit (VPD)	hPa	ERA 5	https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels-monthly-means?tab=download (humidity)	Monthly	0.25 °	2000-2023	2023-12-31
7	Net Solar Radiation	MJ m-2	ERA 5	https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels-monthly-means?tab=download	Monthly	0.25 °	2000-2023	2023-12-31

Methodology

Data Sources (2000–2023):

- ET & Soil Moisture → GLDAS Noah LSM V2.1 (0.25°).
- Rainfall → IMD gridded dataset (0.25°).
- Temperature, Wind Speed, Net Solar Radiation (NSR), VPD → ERA5 reanalysis (0.25°).

Processing:

- Data harmonized to **monthly, seasonal (DJF, MAM, JJAS, ON), and annual scales** at 0.25°.
- **Wind Speed** → derived from u10 & v10 components.
- **VPD** → calculated from ERA5 near-surface temperature & humidity fields.

Spatial Analysis:

- **IDW interpolation** in ArcGIS for rainfall & temperature variability.
- State-wise and regional (Southern Peninsular India) zonal statistics.

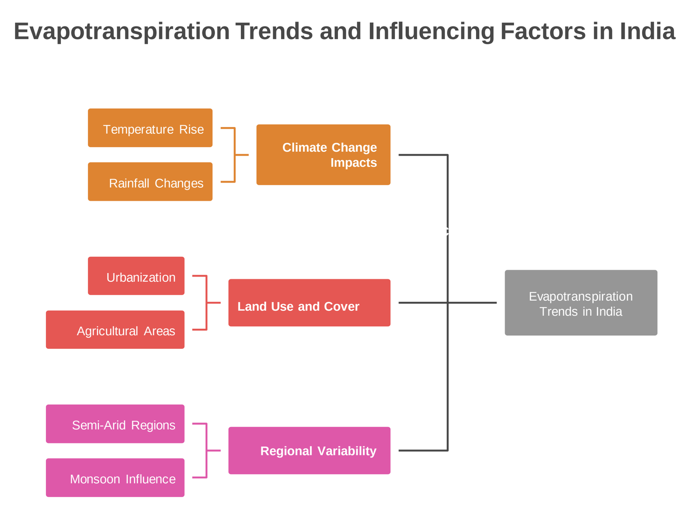
Trend Analysis:

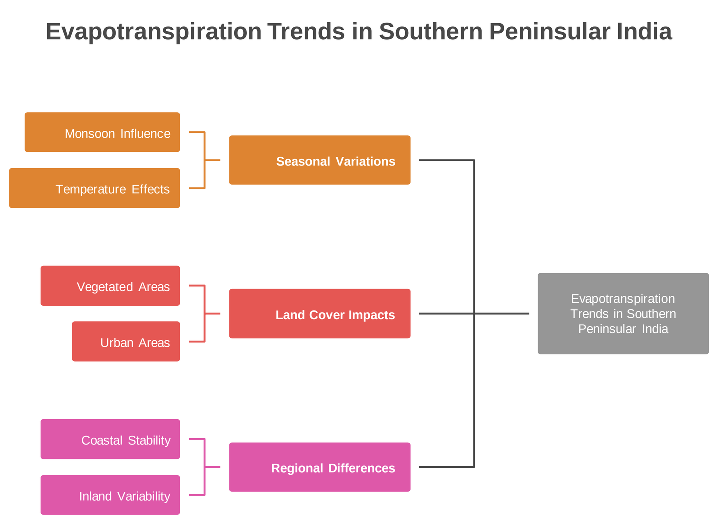
- **Mann–Kendall test** → identifies monotonic trends.
- **Sen's slope estimator** → quantifies trend magnitude (change/year).

Variability Assessment:

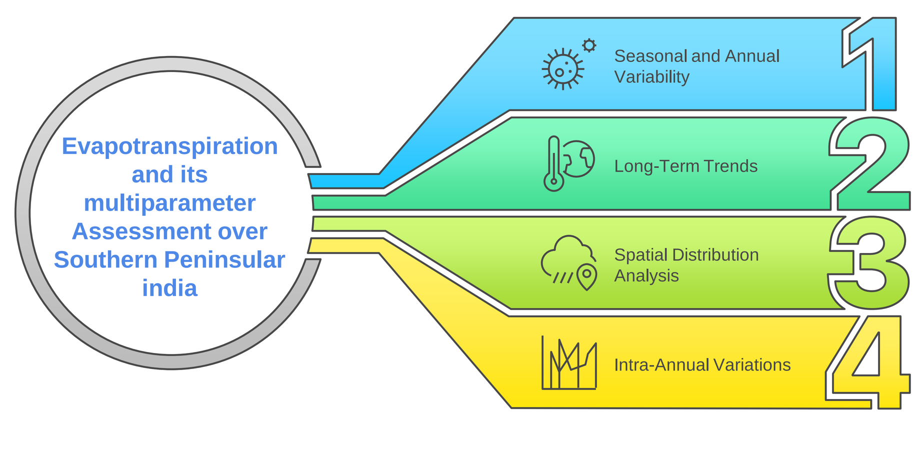
- **Standard Deviation (SD)** → interannual variability.
- **Coefficient of Variation (CV)** → relative variability & climate-sensitive hotspots.

Research Overview





Objectives



Study Area

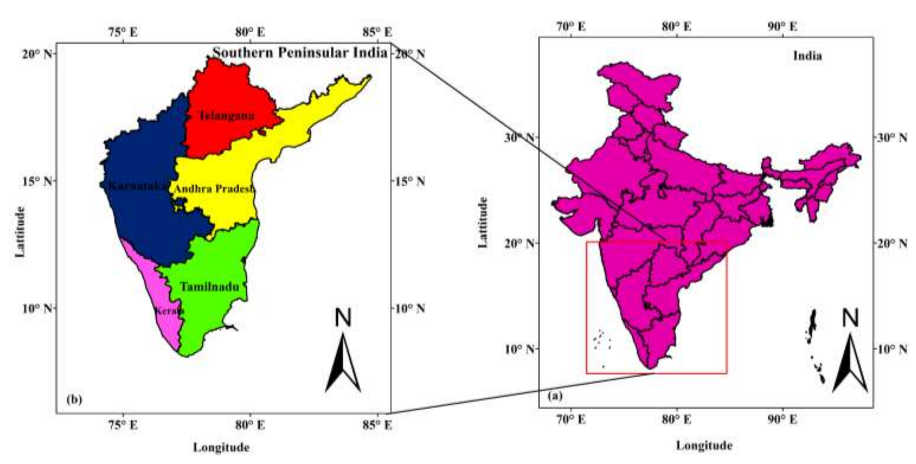


Fig. 1. (a) Location map of Southern Peninsular India(Highlighted with red square box in india) in India (b) the geographical location of the study area.

- ❑ Located south of Vindhya–Satpura ranges; bounded by Arabian Sea (W), Bay of Bengal (E), Indian Ocean (S).
- ❑ Covers Andhra Pradesh, Telangana, Karnataka, Tamil Nadu, and Kerala.
- ❑ Features diverse topography: coastal plains, Western & Eastern Ghats, major river basins.
- ❑ Climatically significant: influences Indian monsoon and seasonal rainfall patterns.
- ❑ Hydrologically important for agriculture, water resources, and ecosystem sustainability.

Results and Discussion

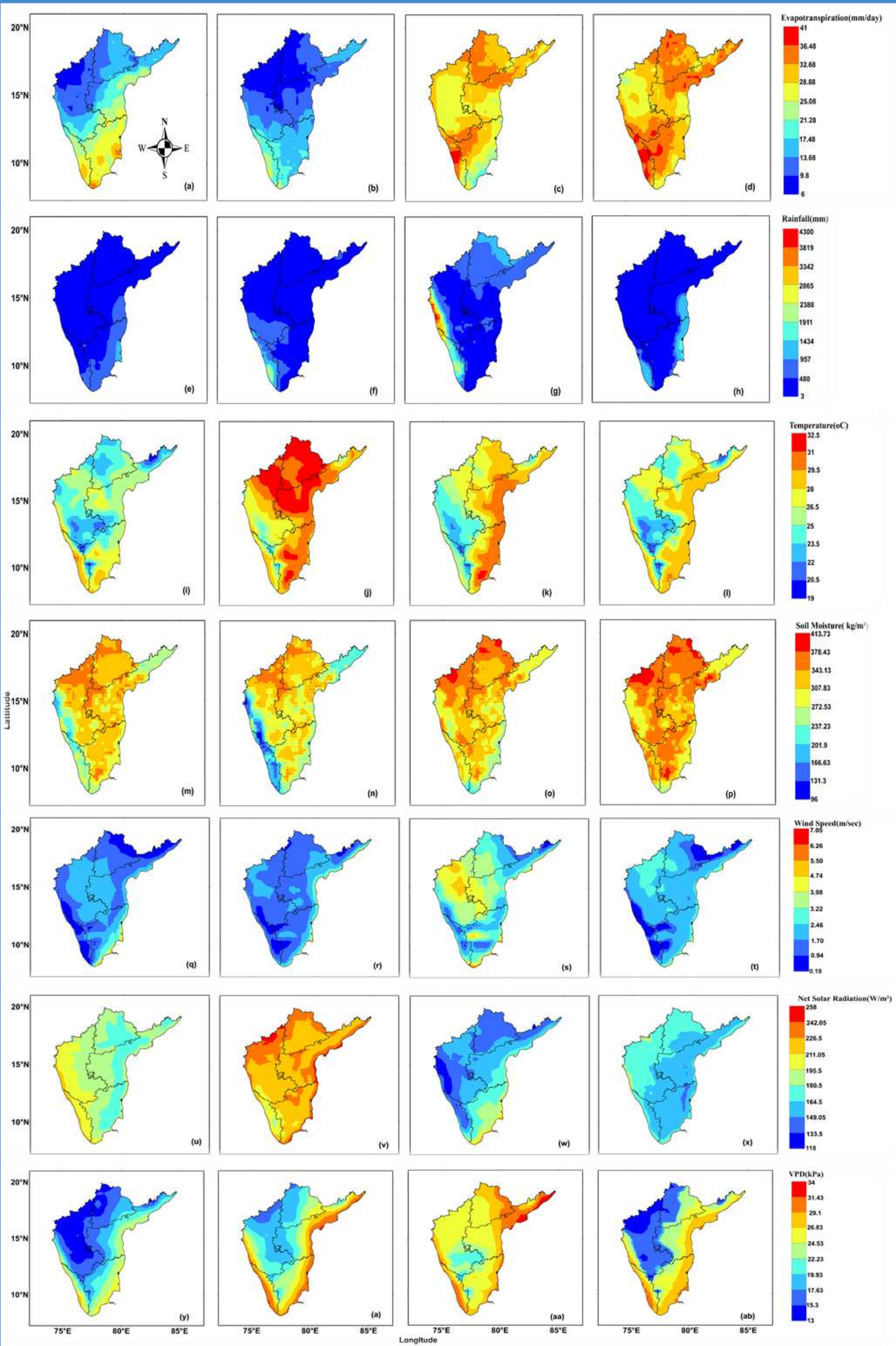


Fig. 2 Illustrates the seasonal spatial variability of key hydro-meteorological variables across Southern Peninsular India during the period from 2000 to 2023. Row 1 represents Evapotranspiration (ET), Row 2 shows Rainfall, Row 3 indicates Temperature, Row 4 contains Soil Moisture, Row 5 displays Wind Speed, Row 6 corresponds to Net Solar Radiation, and Row 7 shows Vapor Pressure Deficit (VPD). The seasons are organized column-wise: Column 1 represents Winter (December–February), Column 2 is Pre-monsoon (March–May), Column 3 corresponds to Monsoon (June–September), and Column 4 reflects Post-monsoon (October–November).

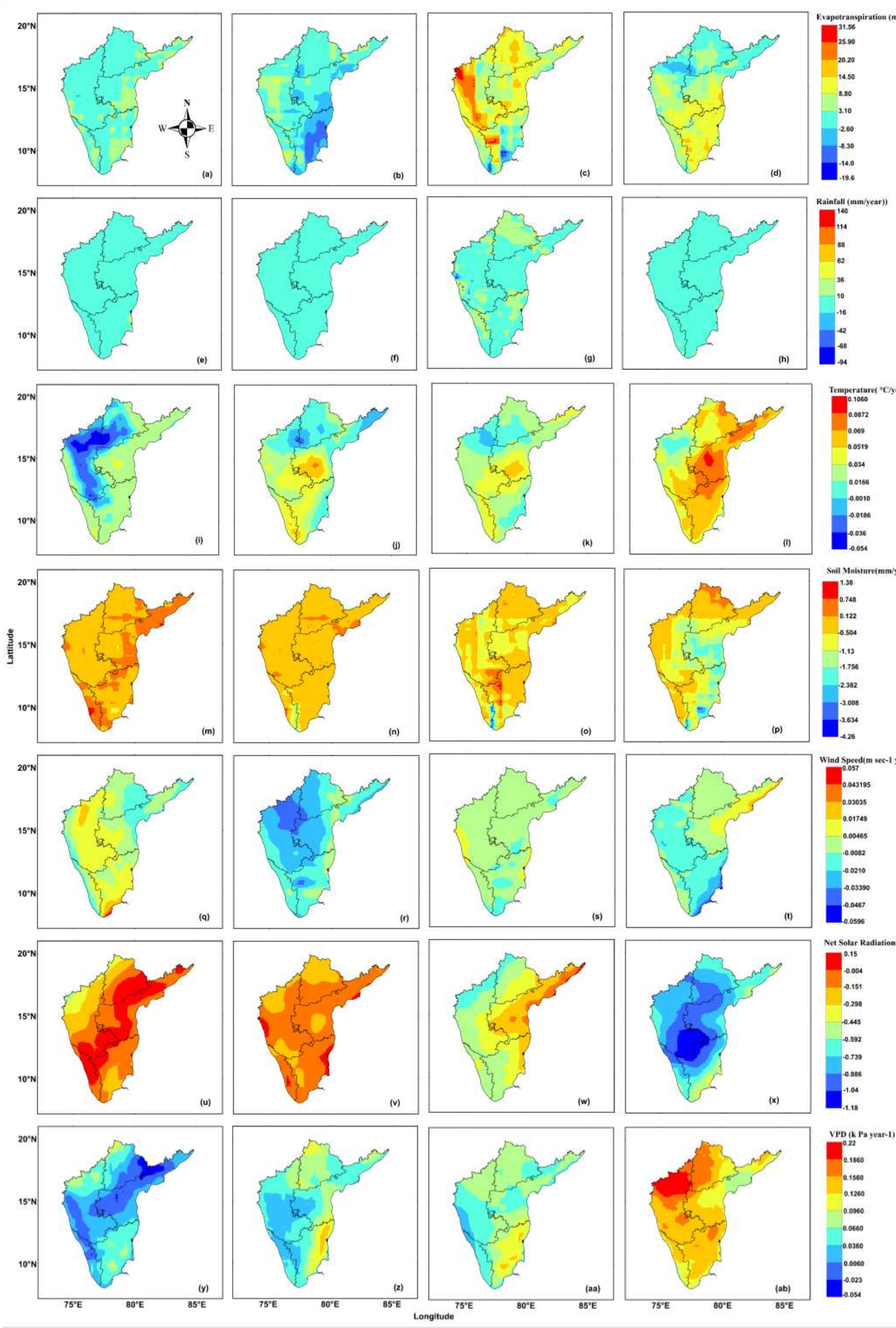


Fig. 3. Presents the spatial trends of key hydro-meteorological variables across Peninsular India for the period 2000–2023. Row 1 represents Evapotranspiration (ET), Row 2 shows Rainfall, Row 3 indicates Temperature, Row 4 contains Soil Moisture, Row 5 displays Wind Speed, Row 6 corresponds to Net Solar Radiation, and Row 7 shows Vapor Pressure Deficit (VPD). The seasons are organized column-wise: Column 1 represents Winter (December–February), Column 2 is Pre-monsoon (March–May), Column 3 corresponds to Monsoon (June–September), and Column 4 reflects Post-monsoon (October–November).

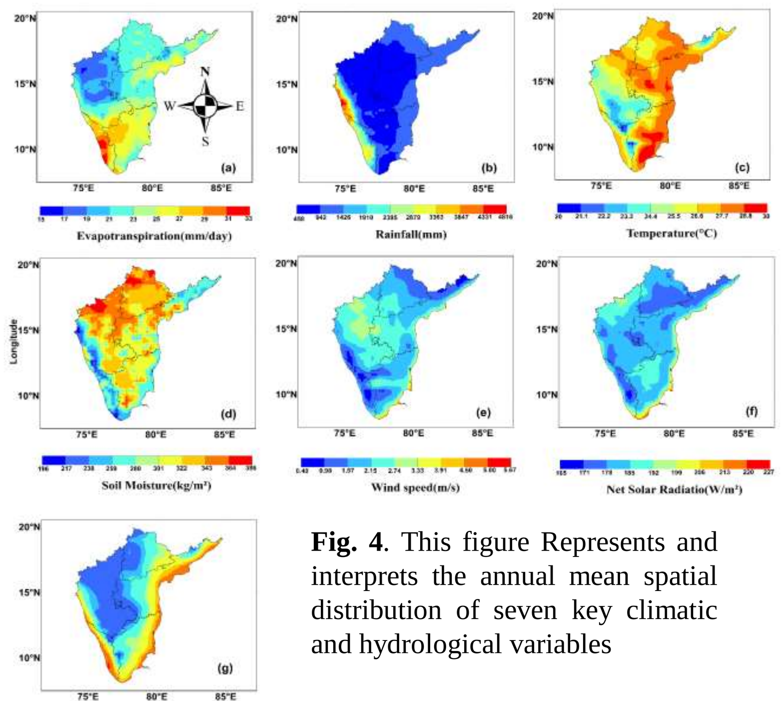


Fig. 4. This figure Represents and interprets the annual mean spatial distribution of seven key climatic and hydrological variables

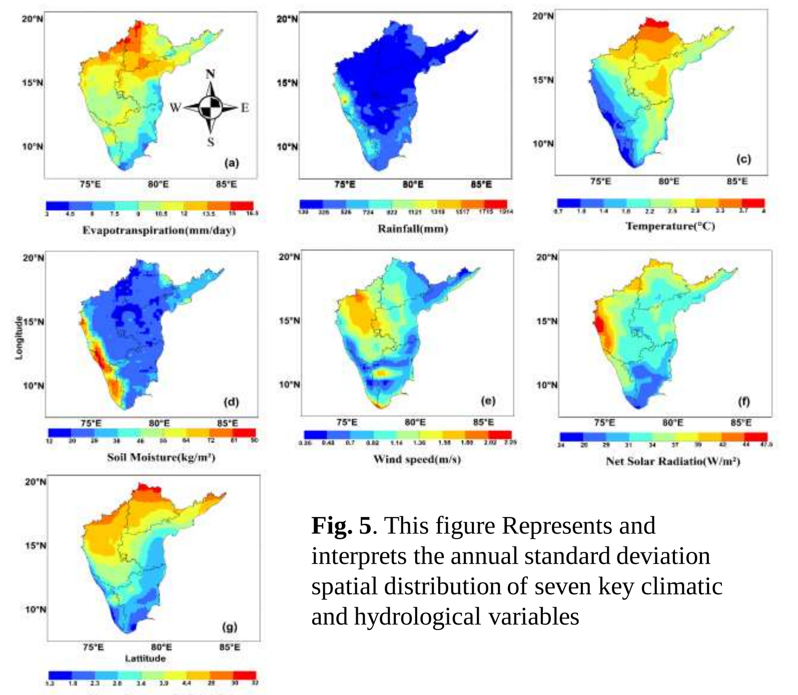


Fig. 5. This figure Represents and interprets the annual standard deviation spatial distribution of seven key climatic and hydrological variables

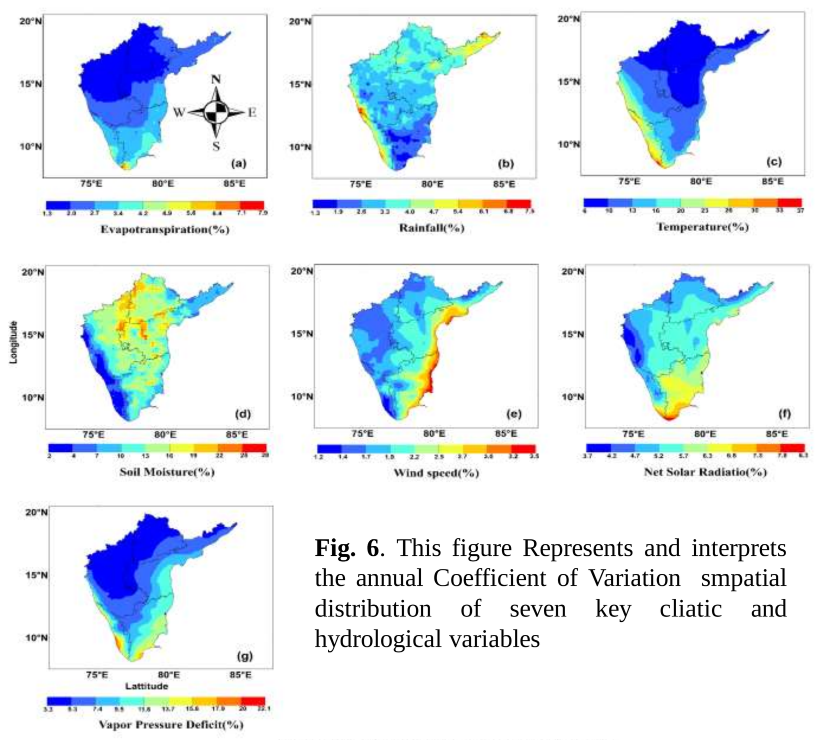
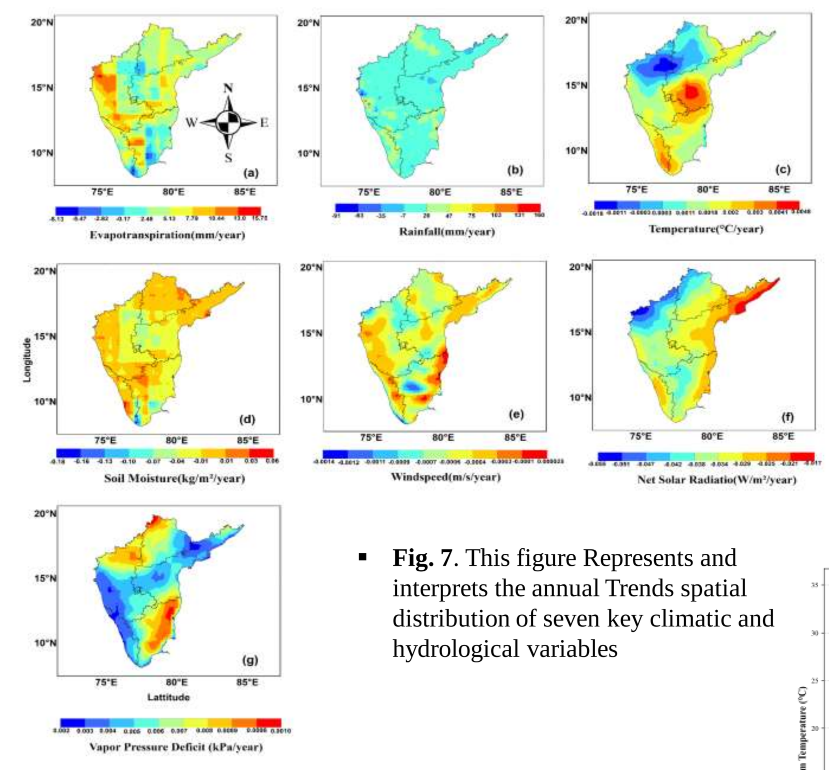


Fig. 6. This figure Represents and interprets the annual Coefficient of Variation spatial distribution of seven key cliatic and hydrological variables



- **Fig. 7**. This figure Represents and interprets the annual Trends spatial distribution of seven key climatic and hydrological variables

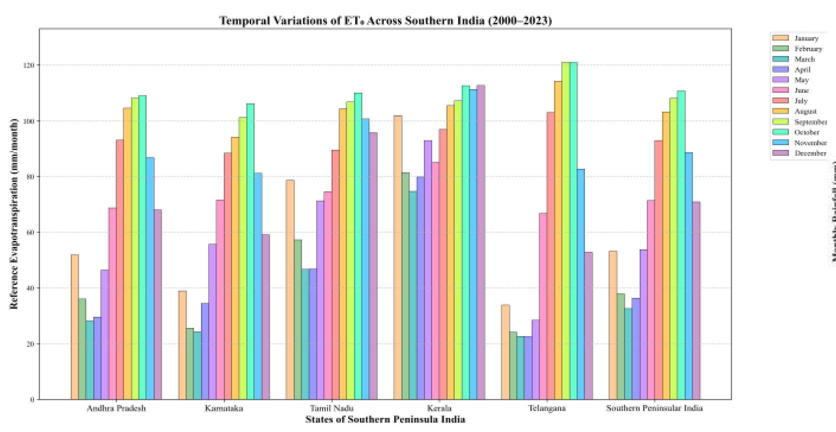


Fig. 8. Illustrates the monthly variation of evapotranspiration (ET) in mm/month across five states

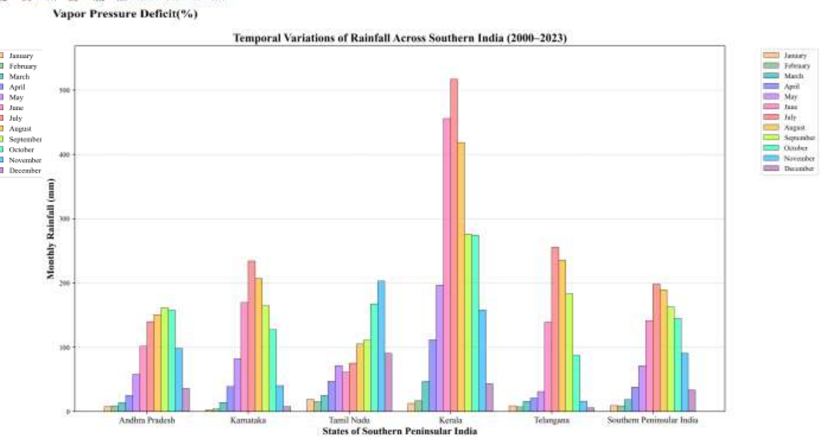


Fig. 9. Illustrates the monthly variation of rainfall (mm)

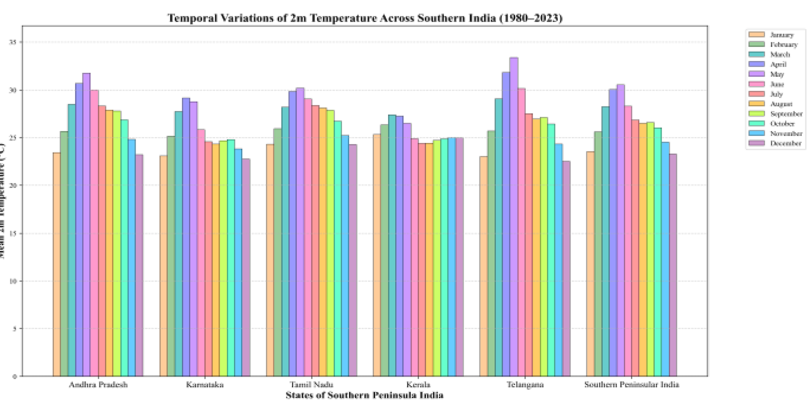


Fig. 10. Illustrates the monthly variation of temperature (°C)

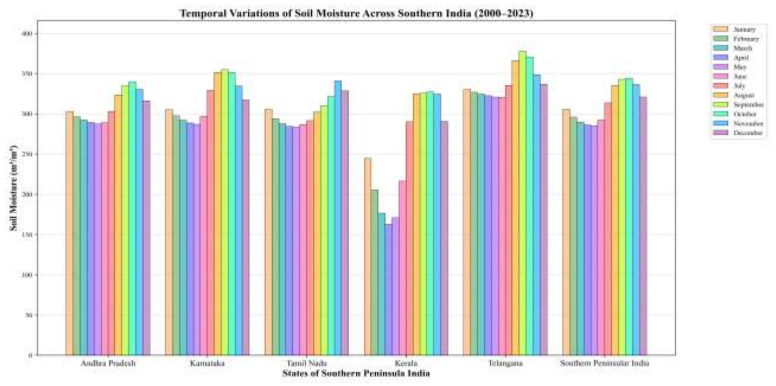


Fig. 11 Illustrates the monthly variation of Soil moisture (m3/m3)

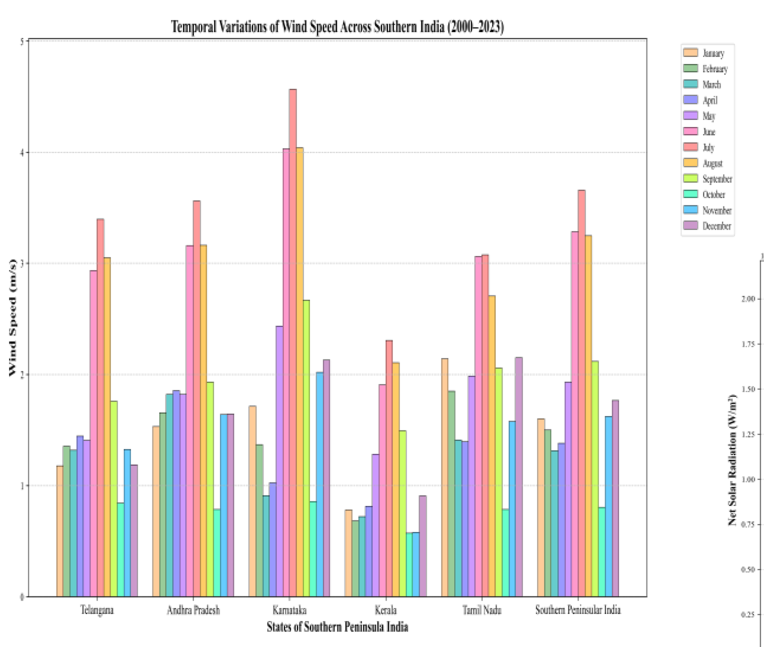


Fig. 12. Illustrates the monthly variation of wind speed (m/s)

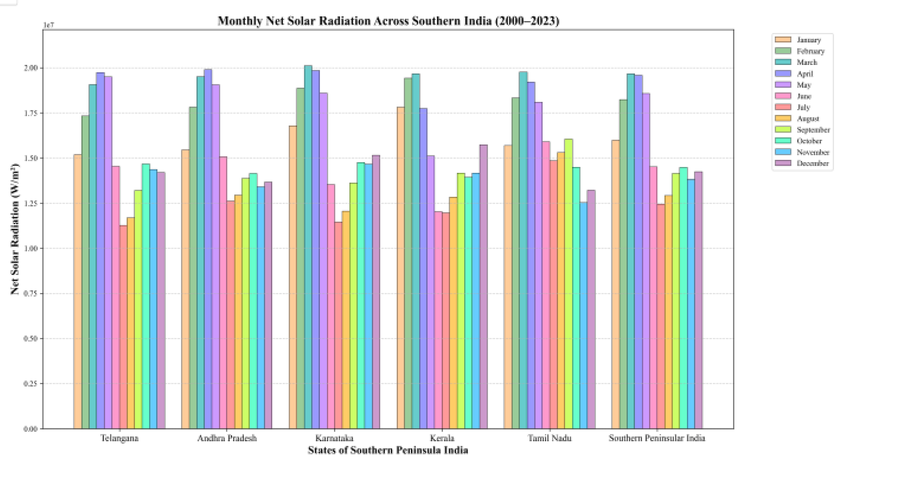


Fig. 13. Illustrates the monthly variation of Net Solar Radiation (W/m²)

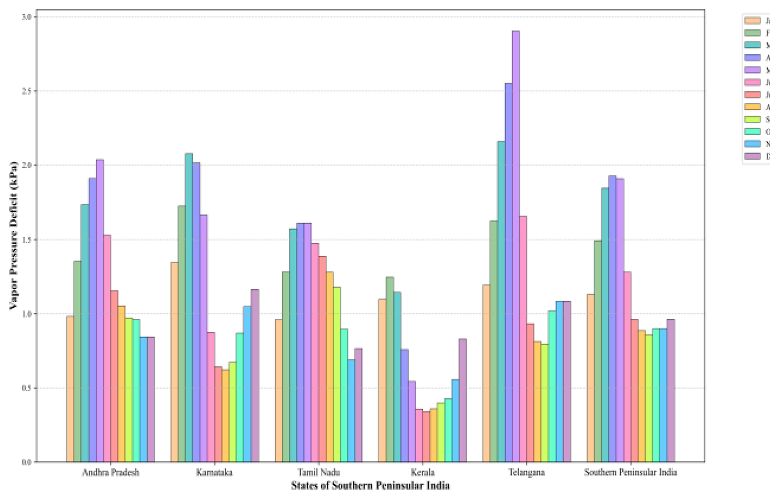


Fig. 14. Illustrates the monthly variation of Vapor Pressure Deficit (kPa)

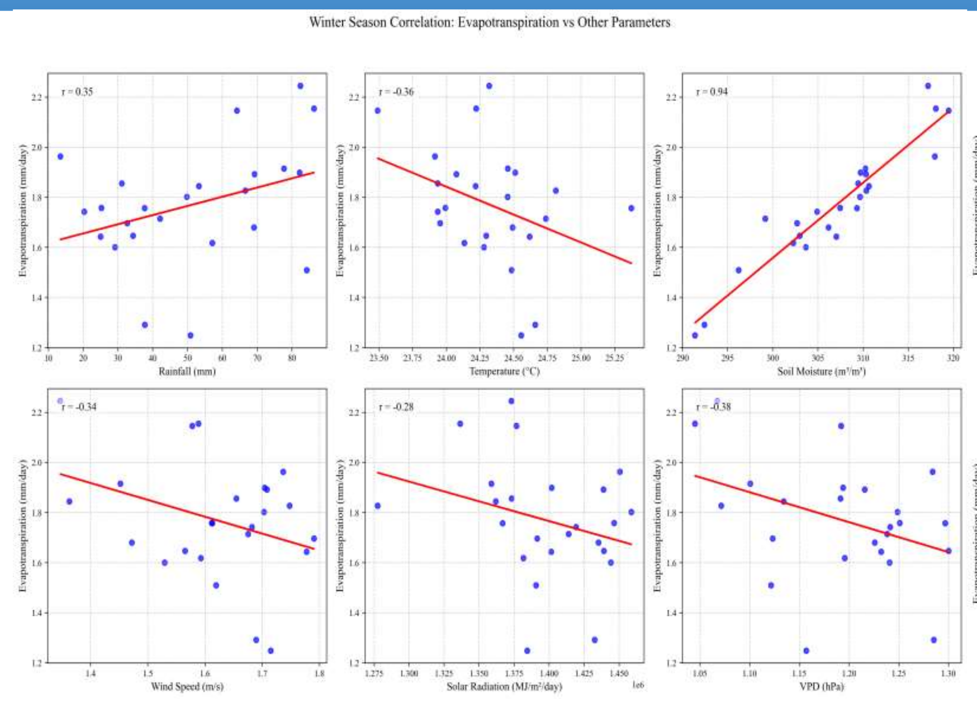


Fig 15: Correlation between Evapotranspiration (ET) and Hydro-Meteorological Drivers across Seasons (2000–2023)

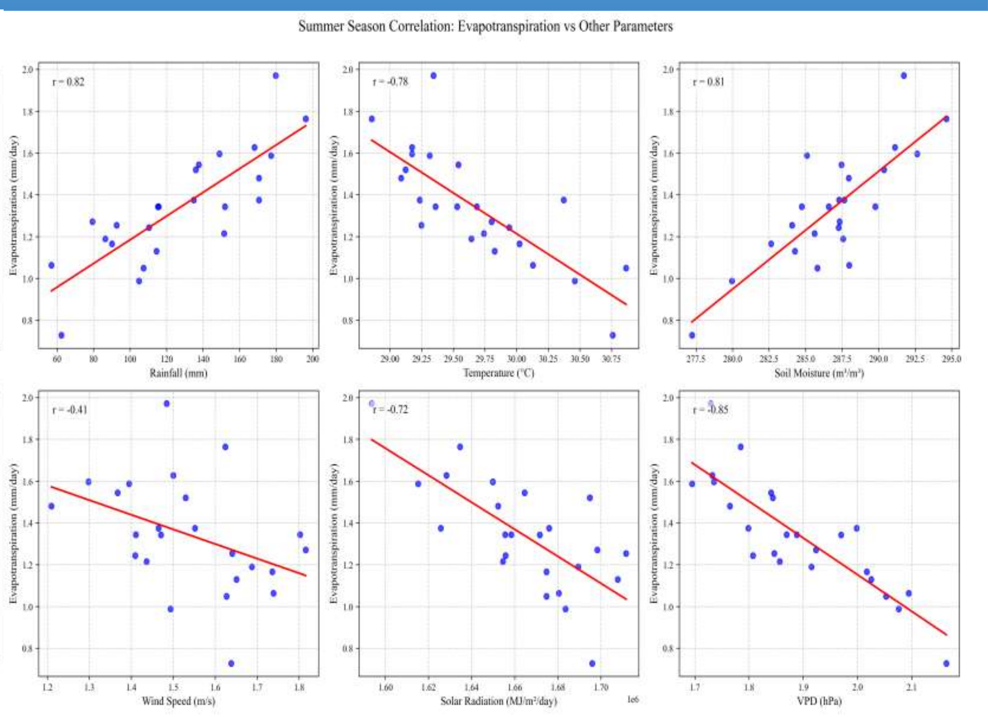


Fig16: Correlation between Evapotranspiration (ET) and Hydro-Meteorological Drivers across Summer (2000–2023

- During winter, **soil moisture availability is the dominant driver of ET**, while energy-related factors (temperature, radiation, VPD) show weak or negative influence. This highlights that ET in winter is **water-limited rather than energy-limited**, especially in semi-arid interiors.

- During summer, **ET is water-limited rather than energy-limited**. Although temperature, radiation, and VPD increase atmospheric demand, **rainfall and soil moisture availability control ET**, making moisture supply the key driver in this season.

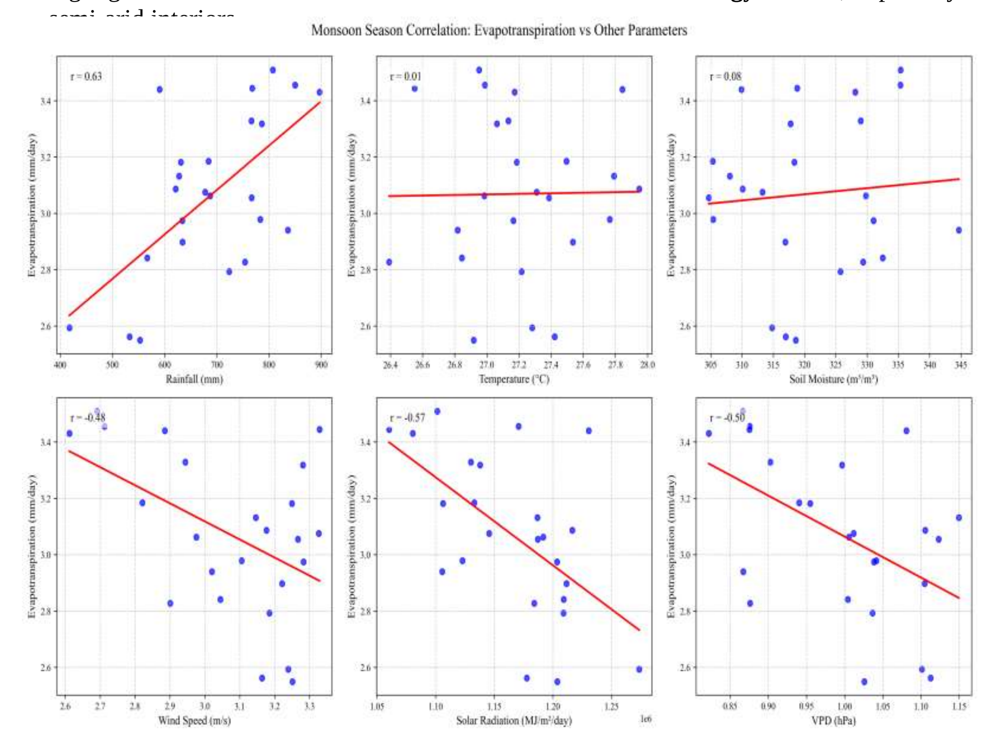


Fig17: Correlation between Evapotranspiration (ET) and Hydro-Meteorological Drivers across Southwest Monsoon (2000–2023)

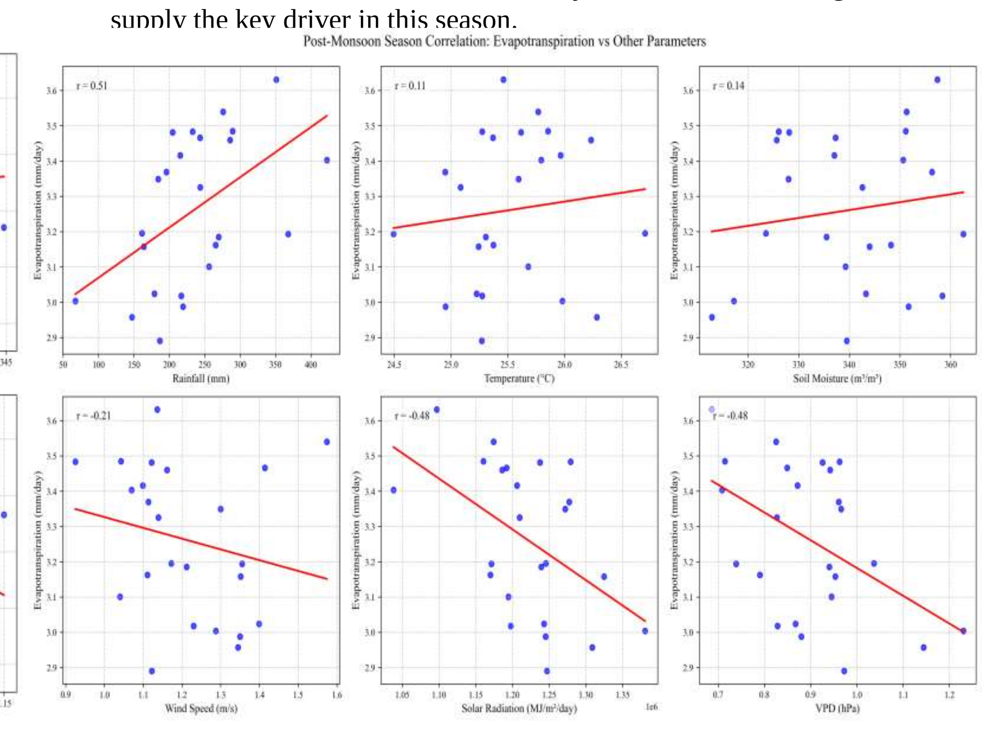


Fig 18: Correlation between Evapotranspiration (ET) and Hydro-Meteorological Drivers across NorthEast Monsoon(2000–2023)

- During monsoon, ET is **primarily controlled by rainfall supply**, while other factors (radiation, wind, VPD) show negative influence due to cloudiness and high humidity. ET is **water-abundant but energy-limited**, making monsoon the most moisture-driven season.

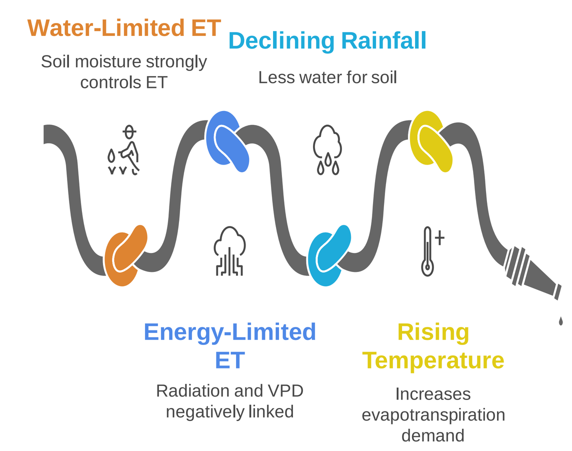
- During post-monsoon, ET is **mainly supported by rainfall recharge**, but overall control is weak from other drivers. Abundant moisture and moderate energy conditions make ET relatively **stable and balanced**, with coastal areas showing higher values.

Summary and Conclusions

ET Controls in Southern Peninsular India

Season	Control	Key Factors
Pre-Monsoon	Peaks	High temperature, radiation, VPD
Winter & Summer	Water-limited	Soil moisture, rainfall
Monsoon & Post-Monsoo	Energy-limited	Radiation, VPD

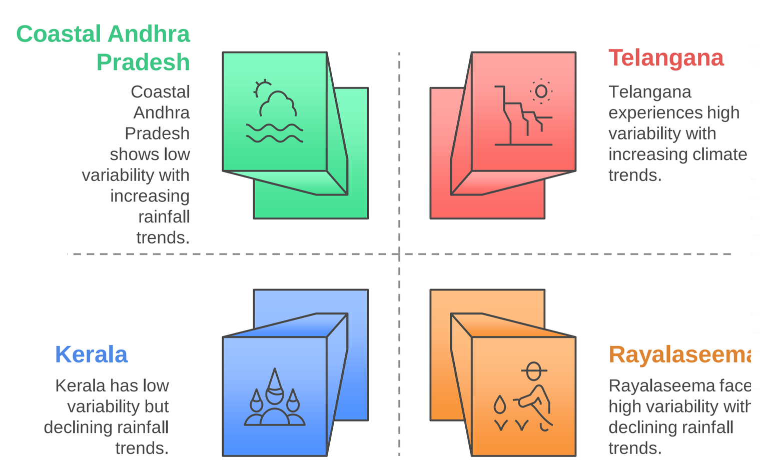
Southern India's Evapotranspiration Challenges

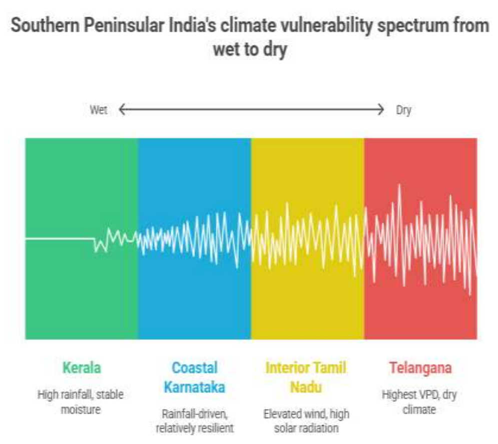


Evapotranspiration Drivers and Their Connection to ET

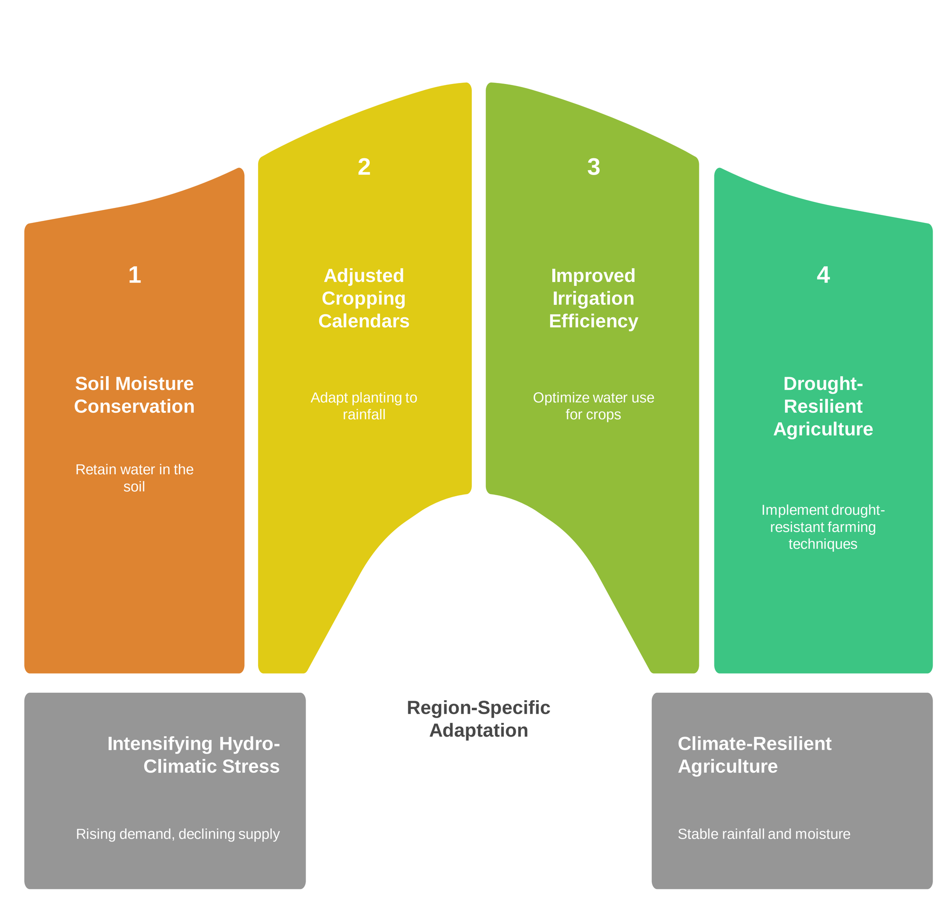
Driver	Connection to ET
Temperature	Amplifies atmospheric evaporative demand
Wind Speed	Boosts ET in wet months
Rainfall	Supplies water, sustains higher ET
Soil Moisture	Water-limited ET in dry interiors
Net Solar Radiation	Reduced radiation lowers ET
Vapor Pressure Deficit	Suppresses atmospheric demand, limiting ET

Climate Variability and Trends in South India





Implications



Submitted to Journal