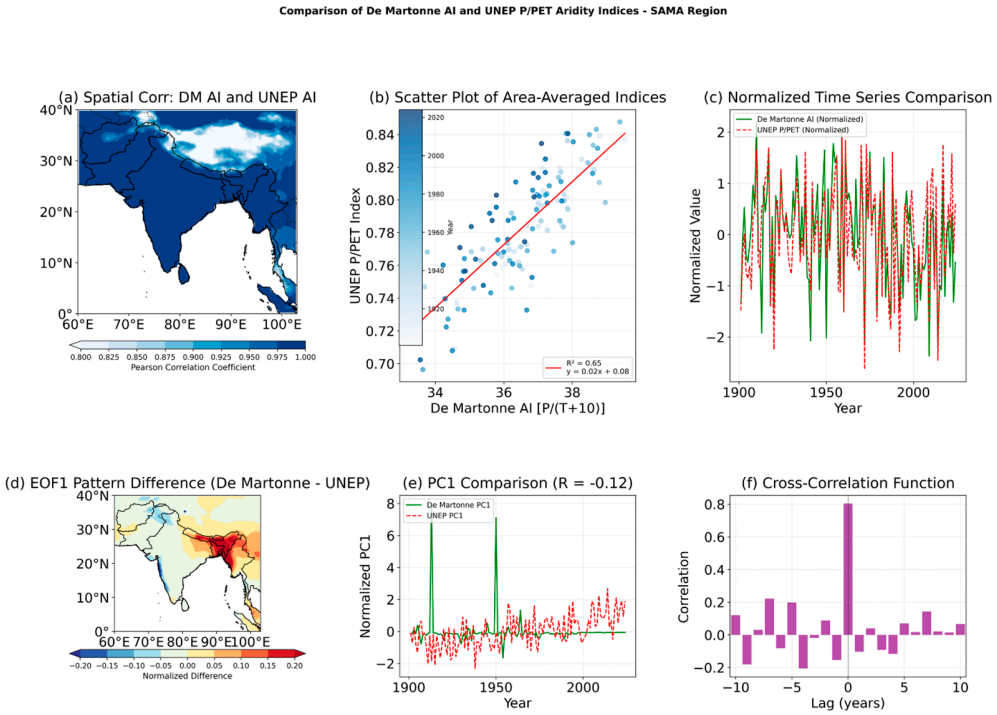


Figure S1 Comparison of De Martonne (P/(T+10)) and UNEP (P/PET) aridity indices across South Asia (60-103°E, 0-40°N): (a) Spatial correlation between indices (b) Scatter plot of area-averaged values with regression line (R^2); (c) Normalized interannual variability time series; (d) Spatial difference in leading EOF; (e) time series (PC1) temporal correlation (R); (f) Cross-correlation function lag between indices. EOF computation performed via SVD after removing temporal means and NaN values.

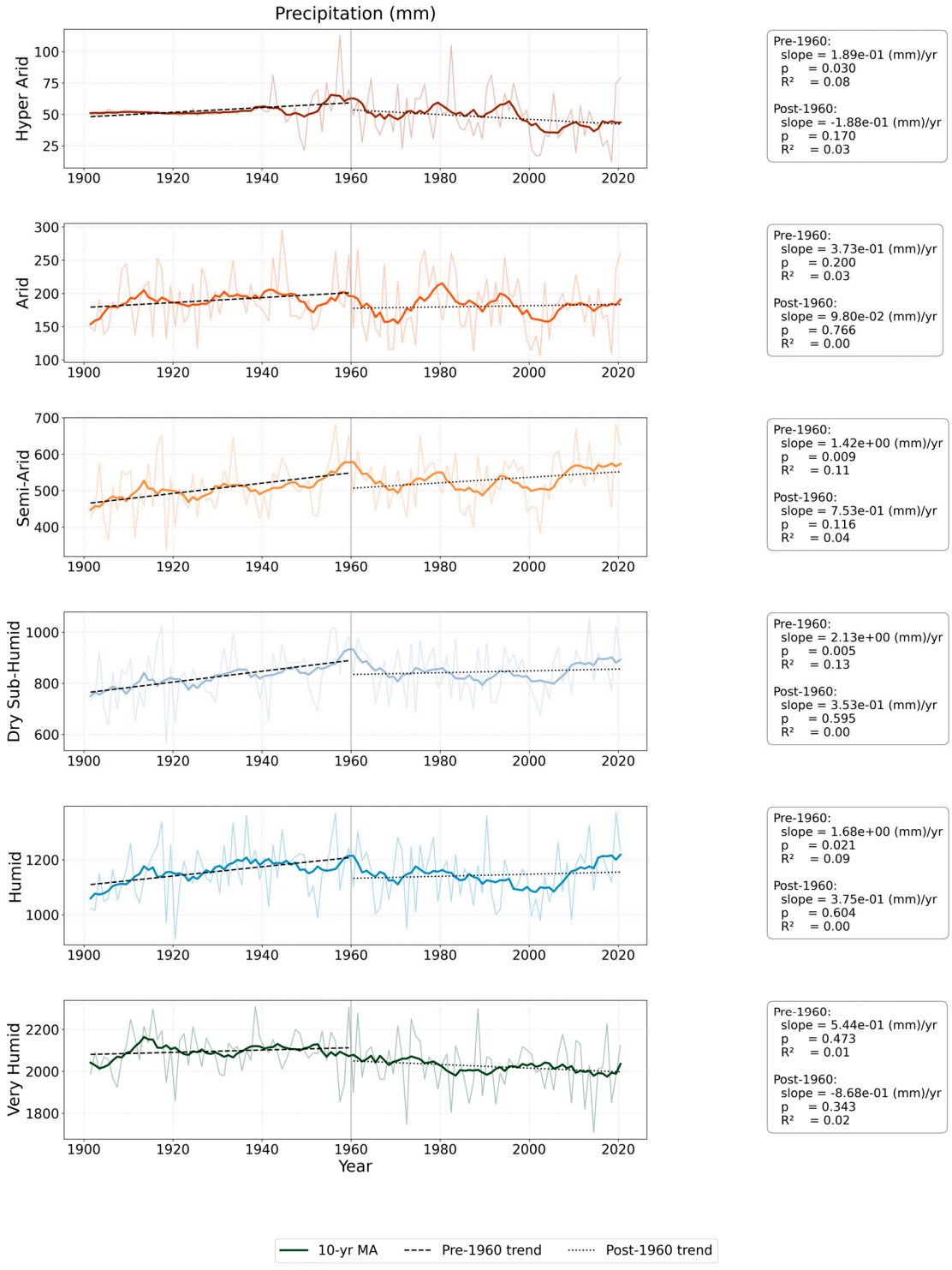


Figure S2 Temporal trends (1901–2020) of climate variables across aridity zones in the South Asian Monsoon region: Precipitation (mm), stratified by UNEP climate classification (as in Fig1.b). Thin lines represent annual values, thick lines show 10-year moving averages and dashed/dotted lines indicate linear trends before and after 1960 (industrial-era inflection point). Data source: CRU TS v4 (1901–2020). Plot generated using Python (xarray, Matplotlib, seaborn).

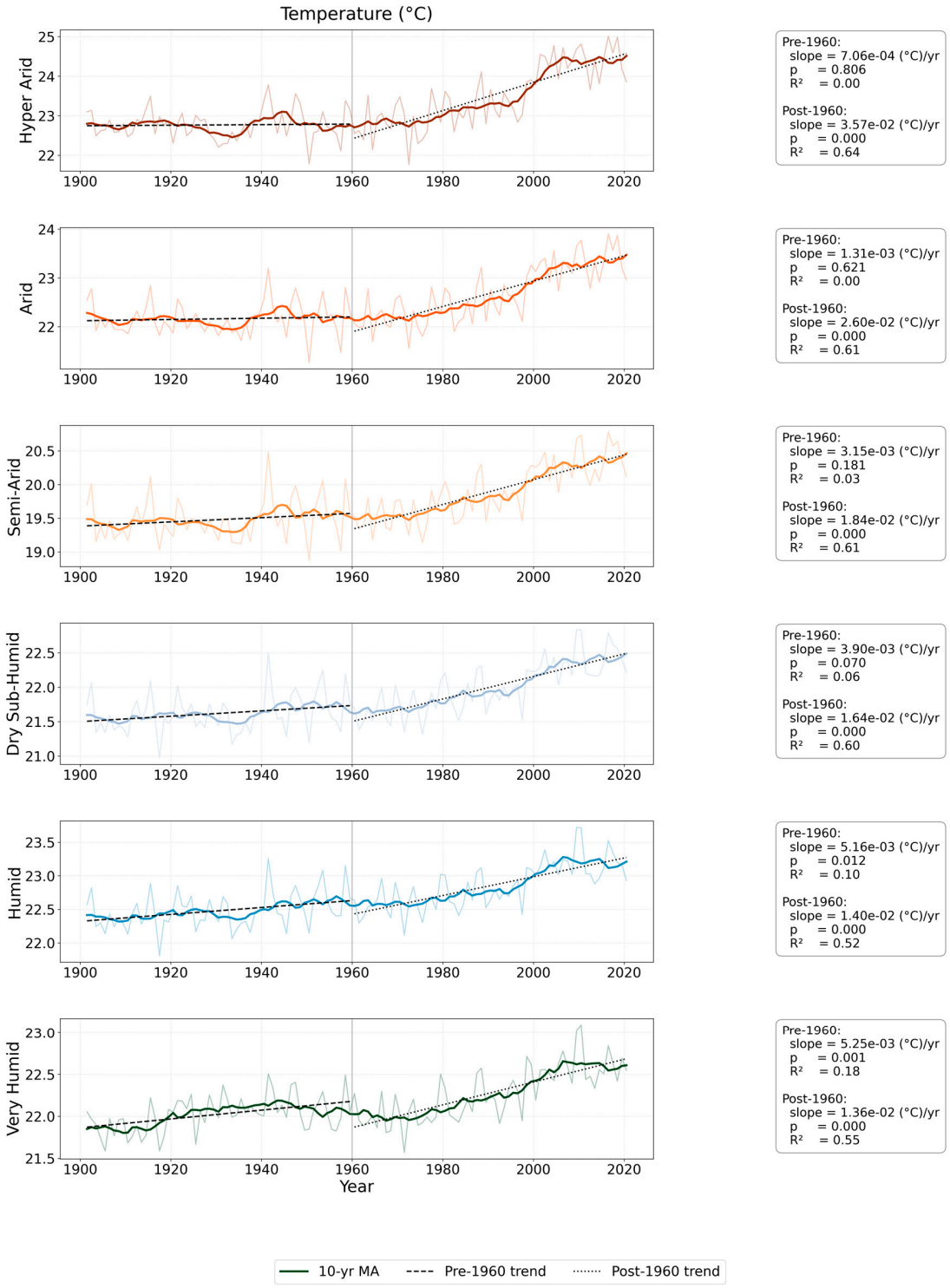


Figure S3 Temporal trends (1901–2020) of climate variables across aridity zones in the South Asian Monsoon region: Temperature (°C), stratified by UNEP climate classification (as in Fig1.b). Thin lines represent annual values, thick lines show 10-year moving averages and dashed/dotted lines indicate linear trends before and after 1960 (industrial-era inflection point). Data source: CRU TS v4 (1901–2020). Plot generated using Python (xarray, Matplotlib, seaborn).

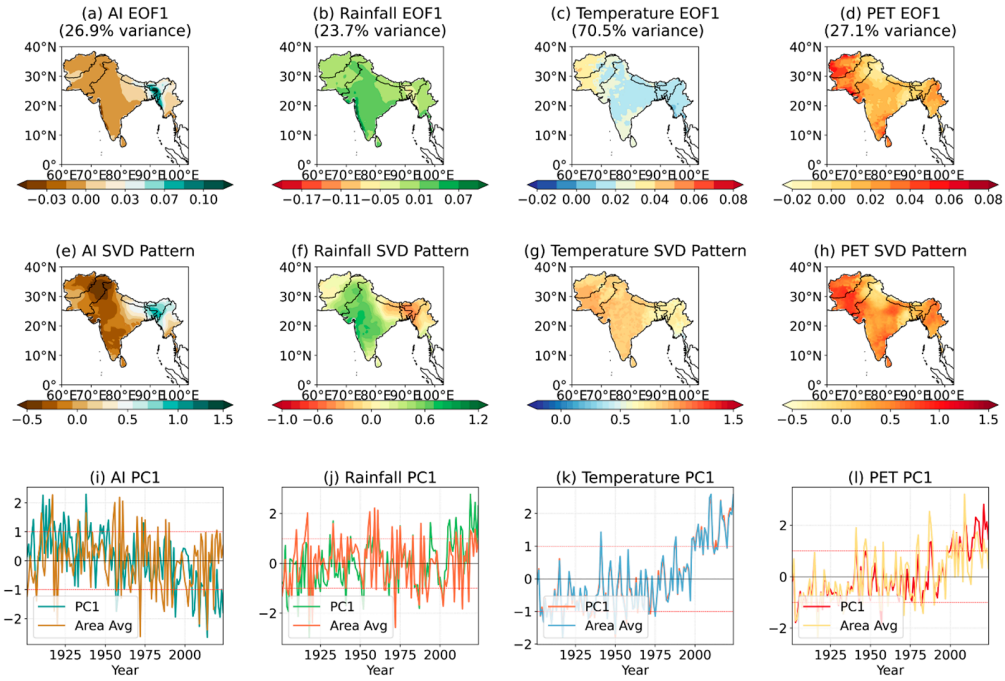


Figure S4 Dominant climate variability modes (1901-2024): (a-d) Leading EOF patterns for (a) Aridity Index, (b) Precipitation, (c) Temperature, and (d) PET. (e-h) SVD correlation patterns showing spatial loadings. (i-l) PC1 time series (blue) versus area-averaged anomalies (orange), demonstrating coherent variability.

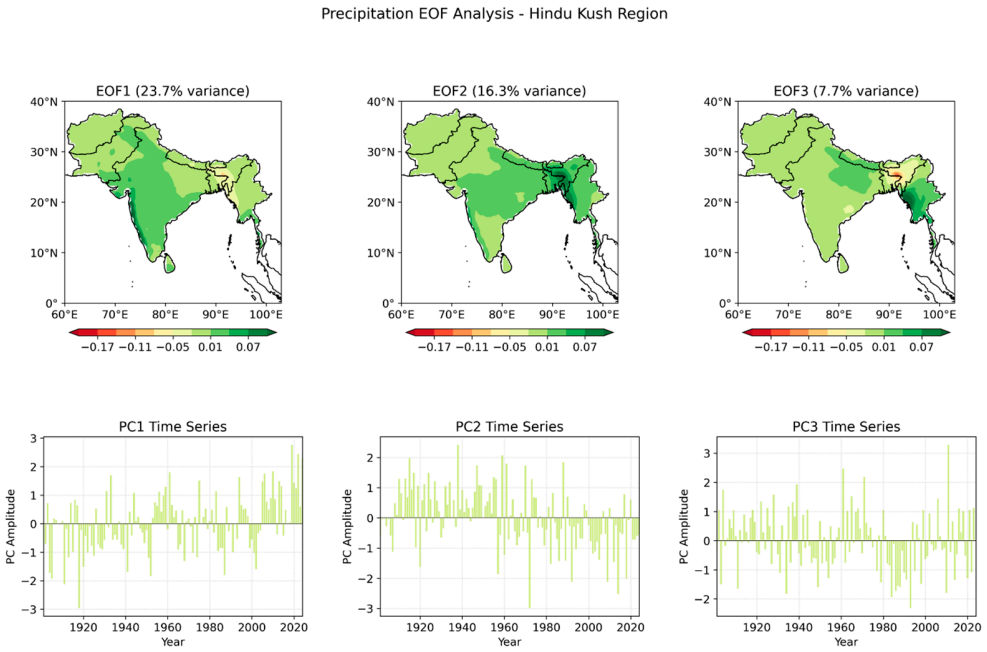


Figure S5 Spatial patterns and principal components of precipitation variability: (a-c) First three EOF modes and (d-f) their corresponding PC time series. Data source: CRU TS4.06 data over South Asia (60-103°E, 0-40°N) using cosine-latitude weighted EOF decomposition.

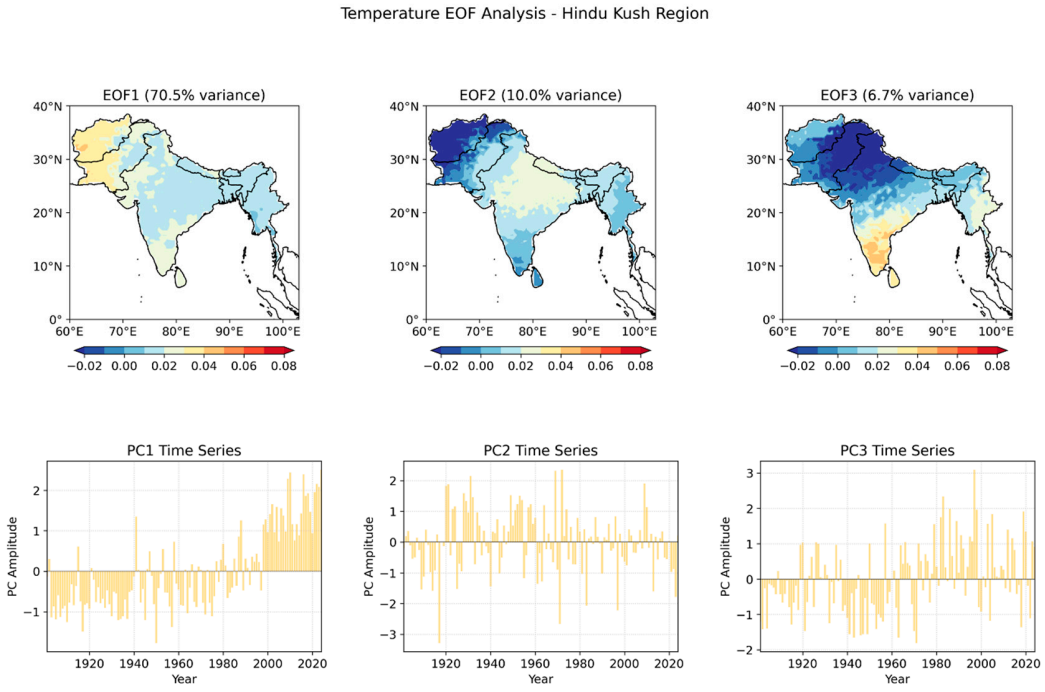


Figure S6 Temperature variability modes: (a-c) EOF spatial patterns and (d-f) associated principal components. Data source: CRU TS4.06 data over South Asia (60-103°E, 0-40°N) using cosine-latitude weighted EOF decomposition.

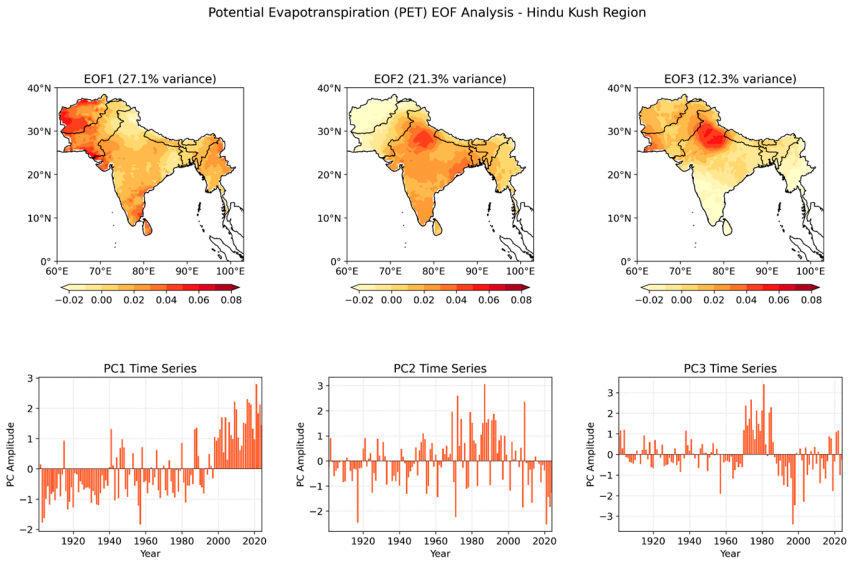


Figure S7 Potential evapotranspiration variability: (a-c) Dominant EOF patterns and (d-f) their temporal components.

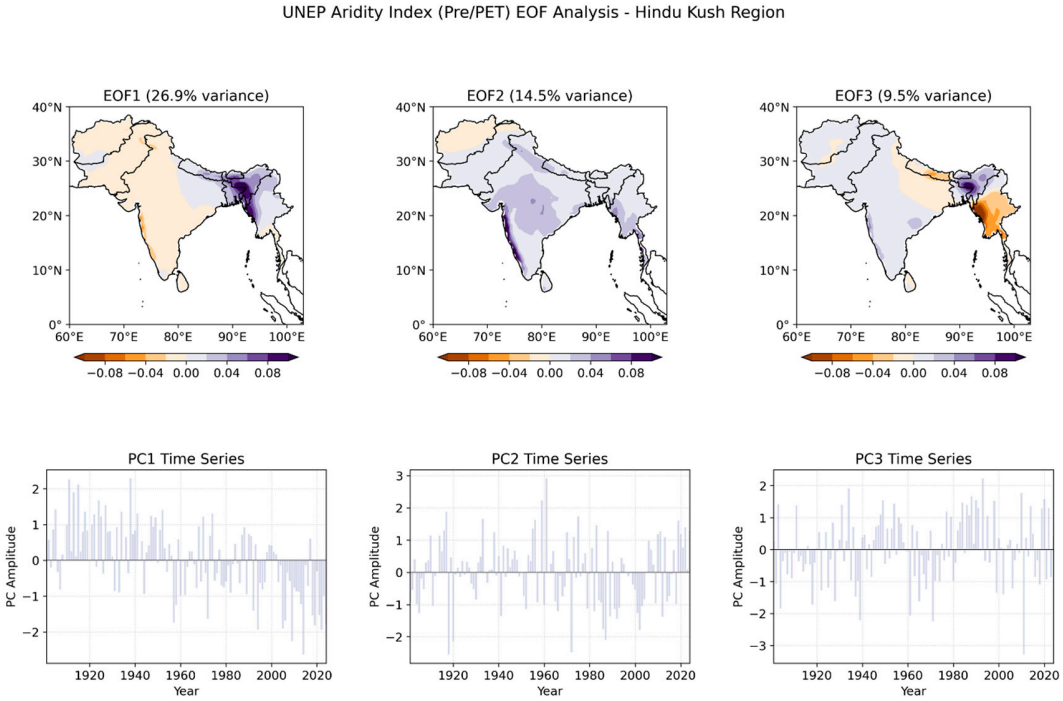


Figure S8 Aridity Index variability: (a-c) Spatial EOF modes and (d-f) PC time series of P/PET variations. Data source: CRU TS4.06 data over South Asia (60-103°E, 0-40°N) using cosine-latitude weighted EOF decomposition.

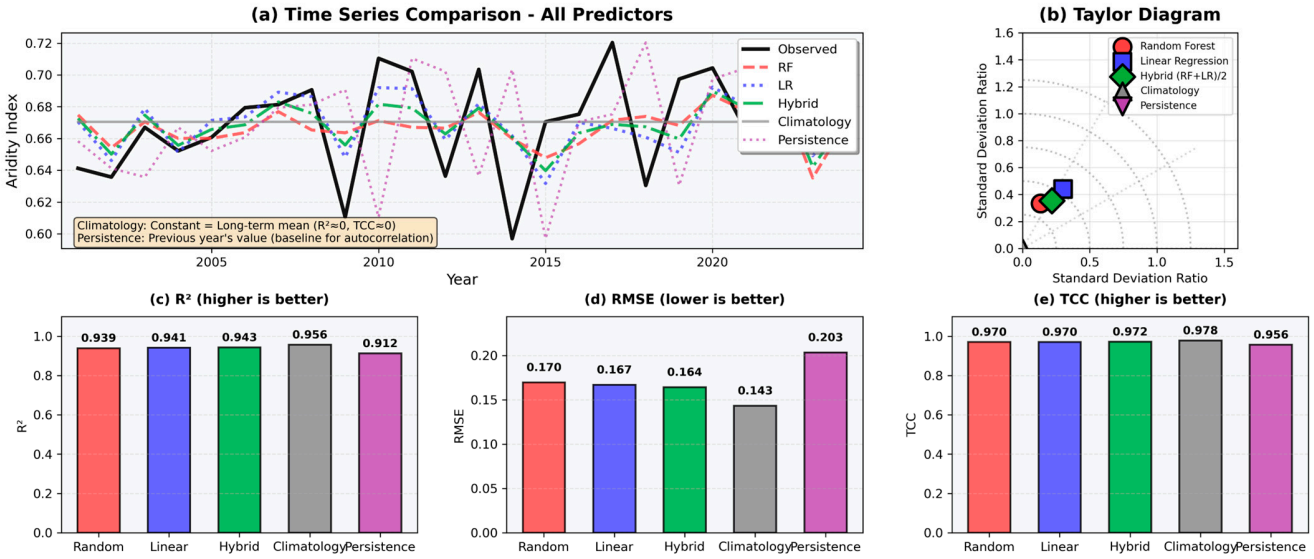


Figure S9 Benchmark comparison of ML models against simple forecasts (2001-2024).(a) Time series of area-averaged AI from observations, three ML models (RF, LR, Hybrid), and two benchmarks: climatology (constant mean) and persistence (previous year's value). (b) Taylor diagram showing correlation, standard deviation ratio, and RMSE. (c-f) Bar charts of R^2, RMSE, TCC, and bias.

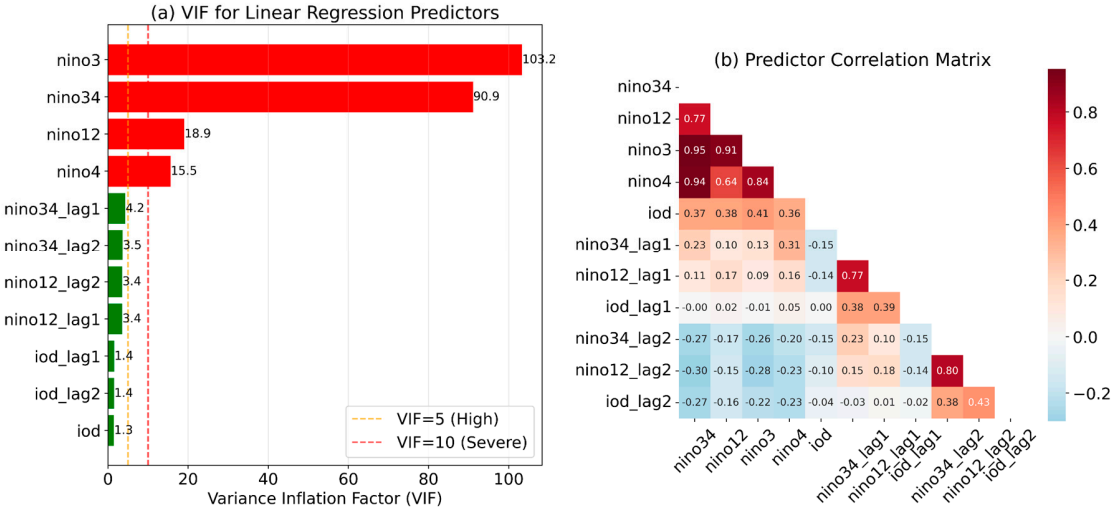
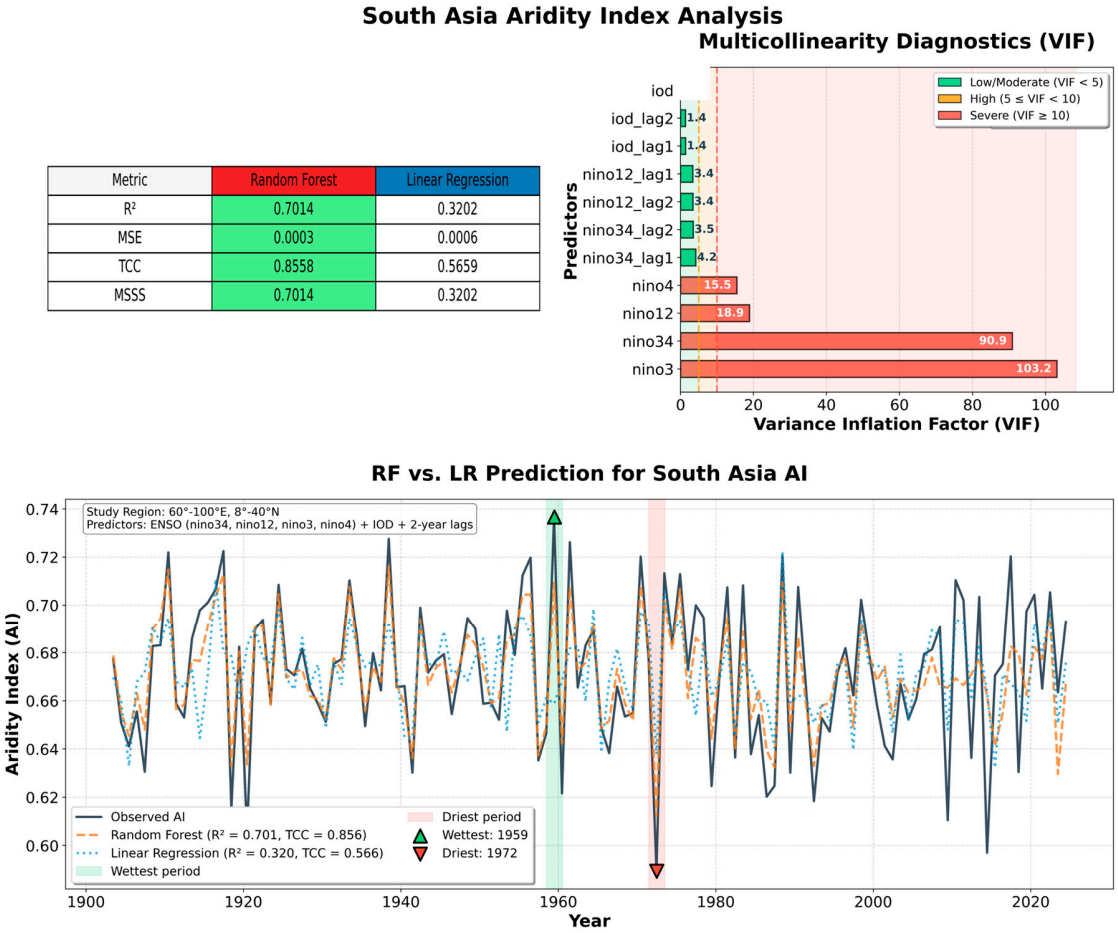


Figure S10 Multicollinearity diagnostics for South Asian aridity predictors. (a) Variance Inflation Factor (VIF) for each predictor with color-coded severity (green: VIF<5, orange: $5 \leqslant$ VIF<10, red: VIF $\geqslant 10$). Dashed vertical lines mark thresholds for high (VIF=5) and severe (VIF=10) multicollinearity. (b) Correlation matrix of all predictors showing pairwise Pearson correlation coefficients.



Metric	Random Forest	Linear Regression
R^2	0.7014	0.3202
MSE	0.0003	0.0006
TCC	0.8558	0.5659
MSSS	0.7014	0.3202

Figure S11 Machine learning analysis of South Asian aridity (60°-100°E, 8°-40°N). Multicollinearity diagnostics (VIF). (Time series of observed versus predicted Aridity Index using RF (red dashed) and Linear Regression (blue dotted) and it table.