Appendix Table

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Table S1-S4

Table S1. Summary of the datasets download link.

Category	Variables and metrics	Abbreviation	Source
Hydroclimate characteristics	Terrestrial water storage	TWS	http://www2.csr.utexas.edu/grace/RL06_mascons.html
	V windspeed at 10 m	VW	https://cds.climate.copernicus.eu/
	U windspeed at 10 m	UW	https://cds.climate.copernicus.eu/
	Surface runoff	SR	https://cds.climate.copernicus.eu/
	Surface latent heat flux	SLHF	https://cds.climate.copernicus.eu/
	Surface pressure	SP	https://cds.climate.copernicus.eu/
	Total evaporation	EVP	https://cds.climate.copernicus.eu/
	Humidity	RH	https://opendata.dwd.de/climate_environment/CDC/grids_germany/
	Soil moisture	SM	https://opendata.dwd.de/climate_environment/CDC/grids_germany/
	Mean Air Temperature	T	https://opendata.dwd.de/climate_environment/CDC/grids_germany/
	Precipitation	P	https://opendata.dwd.de/climate_environment/CDC/grids_germany/
Extreme climate indices	Heavy precipitation days	R10	https://opendata.dwd.de/climate_environment/CDC/grids_germany/
	Very heavy precipitation days	R20	https://opendata.dwd.de/climate_environment/CDC/grids_germany/
	Consecutive dry days	CDD	https://opendata.dwd.de/climate_environment/CDC/grids_germany/

	Consecutive wet days	CWD	https://opendata.dwd.de/climate_environment/CDC/grids_germany/
Large-scale teleconnection patterns	Pacific decadal oscillation	PDO	https://psl.noaa.gov/data/correlation/
	Atlantic multidecadal oscillation	AMO	https://psl.noaa.gov/data/correlation/
	North atlantic oscillation	NAO	https://psl.noaa.gov/data/correlation/
	South oscillation index	SOI	https://psl.noaa.gov/data/correlation/
	Trans-niño index	TNI	https://psl.noaa.gov/data/correlation/
	Nino based index	Nino 1+2 Nino 3 Nino 4 Nino 3.4	https://psl.noaa.gov/data/correlation/
Vegetation characteristics	Normalized difference vegetation index	NDVI	https://search.earthdata.nasa.gov/search
	Enhanced vegetation index	EVI	https://search.earthdata.nasa.gov/search
	Leaf area index	LAI	Google Earth Engine
Terrain characteristic	Latitude	LAT	Google Earth Engine
	Longitude	LON	Google Earth Engine
	Slope	SLO	Google Earth Engine
	Altitude	ALT	Google Earth Engine
Anthropogenic characteristics	Night light index	NL	https://dataverse.harvard.edu/
	Population	POP	https://landscan.ornl.gov/
Landcover characteristics	Shannon's diversity index	SHDI	https://search.earthdata.nasa.gov/search

	Shannon's evenness index	SHEI	https://search.earthdata.nasa.gov/search
	Percentage of landscape	PLAN D_n	https://search.earthdata.nasa.gov/search
Time characteristics	Season	S, A, W	/
	Month-of-year	T	/
Historical drought index	Standardized precipitation evapotranspiration index	SPEI_ N_{t-1}	/

Table S2. AIC and BIC values of different feature combinations.

Features	AIC	BIC
P, SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20, T	-246648.01	-246523.67
P, SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20	-231895.34	-231784.81
P, SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, T	-243395.88	-243285.35
P, SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R20, T	-237604.84	-237494.31
P, SR, SM, SPEI-12$_{t-1}$, R10, R20, T	5722927.20	5723037.72
P, SR, SM, SPEI-11$_{t-1}$, R10, R20, T	-113415.03	-113304.50
P, SR, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20, T	-243974.48	-243863.95
P, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20, T	-209418.44	-209307.91
SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20, T	-246546.13	-246435.60
P, SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10	-228434.94	-228338.23
P, SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R20	-222400.26	-222303.55
P, SR, SM, SPEI-11$_{t-1}$, R10, R20	5736870.68	5736967.39
P, SR, SM, SPEI-11$_{t-1}$, R10, R20	-97270.51	-97173.80
P, SR, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20	-228944.34	-228847.63
P, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20	-193791.14	-193694.43

SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20	-231699.09	-231602.38
P, SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, T	-231315.92	-231219.20
P, SR, SM, SPEI-12$_{t-1}$, R10, T	5725170.80	5725267.51
P, SR, SM, SPEI-11$_{t-1}$, R10, T	-111938.11	-111841.40
P, SR, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, T	-240113.25	-240016.54
P, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, T	-201077.67	-200980.96
SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, T	-243383.43	-243286.72
SR, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R20, T	-234148.72	-234052.01
P, SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R20, T	-200199.12	-200102.40
P, SR, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R20, T	-233259.17	-233162.46
P, SR, SM, SPEI-11$_{t-1}$, R20, T	-103469.02	-103372.31
P, SR, SM, SPEI-12$_{t-1}$, R20, T	5741903.09	5741999.80
P, SR, SPEI-11$_{t-1}$, R10, R20, T	-107269.77	-107173.05
P, SR, SM, R10, R20, T	16589390.00	16589486.72
P, SR, SPEI-12$_{t-1}$, R10, R20, T	5723857.24	5723953.95
P, SM, SPEI-12$_{t-1}$, R10, R20, T	5725024.80	5725121.51
SR, SM, SPEI-12$_{t-1}$, R10, R20, T	5724784.50	5724881.22
P, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20, T	-209021.22	-208924.51
P, SM, SPEI-11$_{t-1}$, R10, R20, T	-84797.90	-84701.19
SR, SM, SPEI-11$_{t-1}$, R10, R20, T	-113349.22	-113252.50
SM, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20, T	-205137.29	-205040.58
SR, SPEI-12$_{t-1}$, SPEI-11$_{t-1}$, R10, R20, T	-243873.60	-243776.89

Table S3. Pearson correlation coefficient of different time scale SPEI-N$_{t-1}$ with SPEI-12$_t$.

Different time scales historical drought indices	Correlation with SPEI-12$_t$	Different time scales historical drought indices	Correlation with SPEI-12$_t$

SPEI-12$_{t-1}$	0.141	SPEI-6$_{t-1}$	0.047
SPEI-11$_{t-1}$	0.227	SPEI-5$_{t-1}$	0.044
SPEI-10$_{t-1}$	0.130	SPEI-4$_{t-1}$	0.034
SPEI-9$_{t-1}$	0.086	SPEI-3$_{t-1}$	0.016
SPEI-8$_{t-1}$	0.055	SPEI-2$_{t-1}$	0.017
SPEI-7$_{t-1}$	0.048	SPEI-1$_{t-1}$	0.012

Table S4. Evaluation results for base learners on validation datasets.

Rank	Models	R^2	RMSE
1	XGBoost	0.933	0.124
2	LightGBM	0.925	0.131
3	RF	0.924	0.132
4	GBDT	0.923	0.132
5	CatBoost	0.921	0.135
6	AdaBoost	0.907	0.146
7	MLP	0.860	0.238