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DAR-type model based on "long memory-threshold" structure: a competitor for daily streamflow prediction under changing environment

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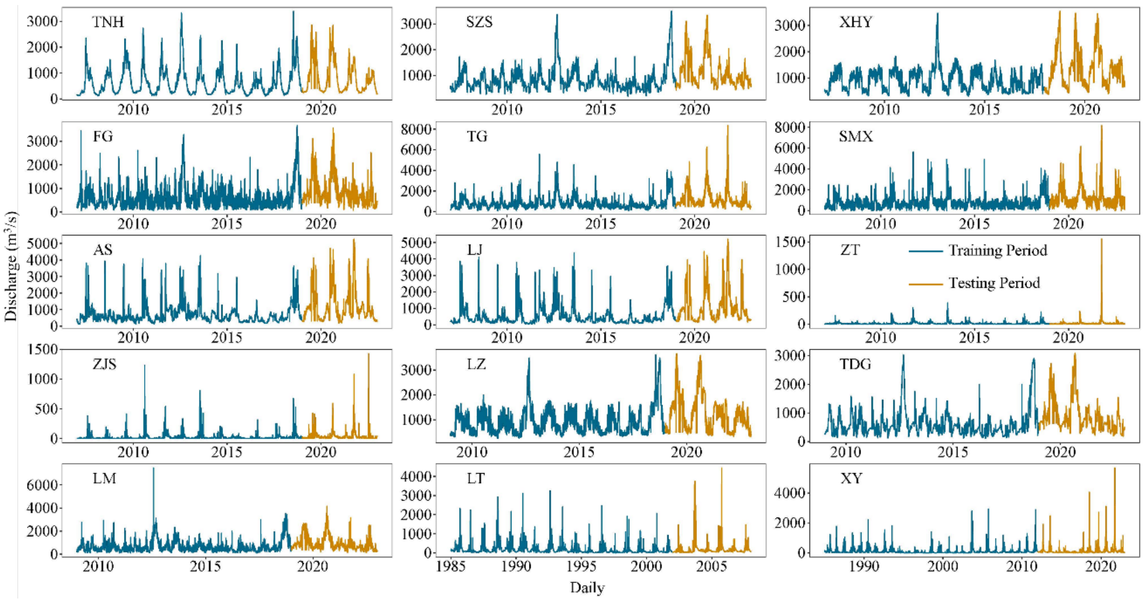

Figure S1: Changes in daily streamflow series at 15 hydrological stations in the study area.

Rescaled range (R/S) analysis method

In this study, the rescaled range (R/S) analysis method is employed to calculate the Hurst exponent (H) of daily streamflow time series from 15 hydrology station. For time series X_t of length T with $t = 0,1,\cdots,T$, the R/S analysis proceeds as follow:

First, calculate the increments of the time series $x_t = X_t - X_{t-1}$ with $t = 0,1,\cdots,T$ and divides them into N adjacent sub-interval I_n, for $n = 1,\cdots,N$, of length v while $Nv = T$. For each sub-interval the mean value is computed, and a cumulative deviation series y_t is constructed by accumulating deviations from this mean.

Subsequently, the range $R_{I_n} = max_{I_n}(y_t) - min_{I_n}(y_t)$ of the cumulative deviation series y_t and a standard deviation S_{I_n} of the original increment time series for each sub- interval are calculated. Each range is divided by its corresponding standard deviation to obtain the standardized rescaled range. Finally, the average rescaled range $(R/S)_v$ for the given sub-period length is calculated by averaging across all sub-intervals. Rescaled ranges scale as $(R/S)_v \propto v^H$.

Significance test of Hurst values for 15 stations

To assess the statistical significance of the H estimated using the R/S method, a confidence interval for the test statistic was constructed based on the Monte Carlo simulation approach. Under the null hypothesis, the time series is assumed to exhibit no long-term memory, i.e., H=0.5, corresponding to a Gaussian white noise process. Specifically, for each hydrological station, 1,000 synthetic Gaussian white noise sequences of the same length as the observed daily streamflow series were generated. The R/S analysis was then applied to each simulated series to estimate the Hurst exponent, and the 95% confidence interval was derived from the resulting distribution. If the H value of the observed series lies outside this interval (at a significance level of $p<0.05$), the time series is considered to exhibit statistically significant long-term memory. As shown in Table S1, all 15 hydrological stations demonstrate significant long-term persistence in their daily streamflow time series.

Table S1. Significance test of H value of daily streamflow time series at 15 hydrological stations

Station	2.50%	97.50%	H	p	Station	2.50%	97.50%	H	p
TNH	0.49	0.60	0.82	<0.05	ZT	0.49	0.60	0.79	<0.05
SZS	0.49	0.60	0.86	<0.05	ZJS	0.48	0.61	0.69	<0.05
XHY	0.49	0.61	0.86	<0.05	LZ	0.49	0.61	0.94	<0.05
FG	0.48	0.60	0.83	<0.05	TDG	0.48	0.61	0.83	<0.05
TG	0.48	0.60	0.84	<0.05	LM	0.49	0.61	0.87	<0.05
SMX	0.48	0.61	0.84	<0.05	LT	0.48	0.59	0.76	<0.05
AS	0.48	0.60	0.84	<0.05	XY	0.48	0.58	0.80	<0.05
LJ	0.49	0.60	0.84	<0.05					

The daily streamflow time series exhibits seasonal characteristics due to the cyclical nature of the four seasons. Figure 4 and Table S1 examine the presence of long-term memory in the daily streamflow series based on the autocorrelation function (ACF) and Hurst exponent (H), respectively, and demonstrate whether seasonality influences the manifestation of long memory. The results show that, after deseasonalization (as detailed in Section 3.1), the ACF of the daily streamflow series decays more slowly, indicating stronger persistence. In addition, the H values of the daily streamflow series at 15 hydrological stations, calculated using the rescaled range (R/S) analysis method, are all greater than 0.5, suggesting the existence of long-term memory. The H values of the original series range from 0.69 to 0.94, which are lower than those of the deseasonalized series. The specific steps of the R/S method are presented in the supplementary manuscript, and Table S1 further shows the statistical significance of the H values of each station.

Table S2: *p* value of unit root test for daily streamflow time series

Stations	Original			De-seasonal standardization			Fractional difference		
	ADF	PP	KPSS	ADF	PP	KPSS	ADF	PP	KPSS
TNH	>0.1	<0.05	>0.05	<0.05	<0.01	>0.05	<0.01	<0.01	>0.1
SZS	>0.1	<0.01	<0.05	>0.05	<0.01	<0.05	<0.01	<0.01	>0.1
XHY	>0.1	<0.01	<0.05	>0.1	<0.01	<0.05	<0.01	<0.01	>0.1
FG	>0.1	<0.01	<0.05	>0.05	<0.01	<0.05	<0.01	<0.01	>0.1
TG	>0.1	<0.01	<0.05	>0.1	<0.01	<0.05	<0.01	<0.01	>0.1
SMX	>0.1	<0.01	<0.01	>0.1	<0.01	<0.01	<0.01	<0.01	>0.1
AS	>0.1	<0.01	<0.05	>0.1	<0.01	<0.05	<0.01	<0.01	>0.1
LJ	>0.1	<0.01	<0.05	>0.1	<0.01	<0.05	<0.01	<0.01	>0.1
ZT	>0.1	<0.01	>0.1	<0.01	<0.01	>0.1	<0.01	<0.01	>0.1
ZJS	>0.1	<0.01	<0.05	>0.05	<0.01	<0.01	<0.01	<0.01	>0.1
LZ	>0.1	<0.01	<0.05	>0.05	<0.01	<0.05	<0.01	<0.01	>0.1
TDG	>0.1	<0.01	>0.05	>0.05	<0.01	<0.05	<0.01	<0.01	>0.1
LM	>0.1	<0.01	>0.05	>0.05	<0.01	<0.05	<0.01	<0.01	>0.1
LT	>0.05	<0.01	>0.05	<0.01	<0.01	<0.05	<0.01	<0.01	>0.1
XY	>0.1	<0.01	>0.05	<0.05	<0.01	<0.05	<0.01	<0.01	>0.1

Table S3: BDS test of daily streamflow time series

Stations	Original		De-seasonal standardization		Fractional difference	
	Statistics	*p*	Statistics	*p*	Statistics	*p*
TNH	238.861	< 0.01	536.526	< 0.01	151.522	< 0.01
SZS	214.469	< 0.01	236.808	< 0.01	101.006	< 0.01
XHY	755.147	< 0.01	161.921	< 0.01	76.9601	< 0.01
FG	117.495	< 0.01	98.942	< 0.01	45.0023	< 0.01
TG	112.696	< 0.01	146.002	< 0.01	45.6786	< 0.01
SMX	107.53	< 0.01	96.9822	< 0.01	32.3368	< 0.01
AS	130.957	< 0.01	214.708	< 0.01	81.2741	< 0.01
LJ	108.95	< 0.01	192.499	< 0.01	73.743	< 0.01
ZT	79.2369	< 0.01	91.0533	< 0.01	40.5853	< 0.01
ZJS	66.7261	< 0.01	60.0554	< 0.01	38.6579	< 0.01
LZ	221.748	< 0.01	79.6637	< 0.01	25.0695	< 0.01
TDG	159.425	< 0.01	217.897	< 0.01	136.189	< 0.01
LM	90.2421	< 0.01	93.7633	< 0.01	29.9717	< 0.01
LT	125.372	< 0.01	255.146	< 0.01	70.2722	< 0.01
XY	143.41	< 0.01	267.819	< 0.01	77.9509	< 0.01

Table S4: The LM test of daily streamflow time series

Stations	Original		De-seasonal standardization		Fractional difference	
	Statistics	*p*	Statistics	*p*	Statistics	*p*
TNH	4298.98	< 0.01	3580.84	< 0.01	3712.7	< 0.01
SZS	4287.97	< 0.01	3493.27	< 0.01	2518.44	< 0.01
XHY	3705.25	< 0.01	1769.77	< 0.01	1647.48	< 0.01
FG	3614.65	< 0.01	2441.83	< 0.01	881.492	< 0.01
TG	3528.39	< 0.01	2411.24	< 0.01	881.567	< 0.01
SMX	2941.85	< 0.01	1530.06	< 0.01	542.472	< 0.01
AS	4008.39	< 0.01	3628.33	< 0.01	2925.07	< 0.01
LJ	4087.1	< 0.01	3562.17	< 0.01	3076.79	< 0.01
ZT	2146.79	< 0.01	2721.1	< 0.01	819.449	< 0.01
ZJS	470.058	< 0.01	1736.57	< 0.01	173.742	< 0.01
LZ	3274.57	< 0.01	1682.35	< 0.01	392.955	< 0.01
TDG	3559.98	< 0.01	3067.69	< 0.01	1963.78	< 0.01
LM	1900.84	< 0.01	1903.24	< 0.01	22.1043	< 0.01
LT	1936.85	< 0.01	3692.69	< 0.01	384.945	< 0.01
XY	3619.99	< 0.01	6059.19	< 0.01	963.709	< 0.01