Supplement

This supplementary material includes geographical division map of the Loess Plateau (2000), the calculation methods and results for the Standardized Precipitation Evapotranspiration Index (SPEI) and the Standardized Soil Moisture Index (SSMI), as well as the q-value and corresponding p-value for the OPGD model driving factor.

S.1 Geographical Division Map of the Loess Plateau (2000)

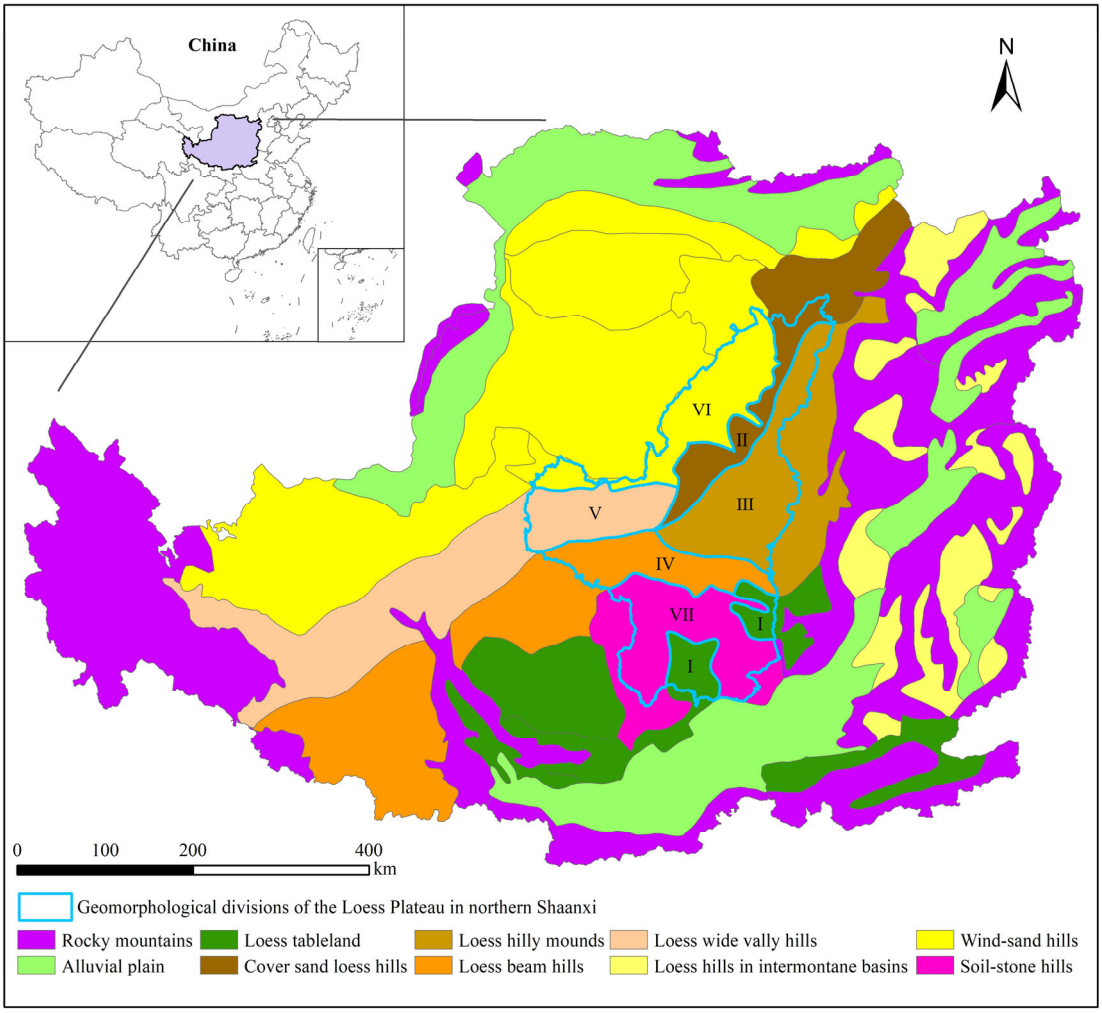


Figure S1 Geographical Division Map of the Loess Plateau (2000) [34].

S.2 Standardized Precipitation Evapotranspiration Index（SPEI）

This study assesses and monitors meteorological drought conditions in northern Shaanxi's Loess Plateau using the Standardized Precipitation Evapotranspiration Index (SPEI). SPEI takes the climate water balance as input, evaluating the cumulative difference in precipitation and potential evapotranspiration across various temporal scales [1]. The computation steps are as follows:

Step 1: Calculating the water deficiency series:

$$D_i = P_i - PET_i \quad \text{(s-1)}$$

where P_i is the monthly precipitation (mm); PET_i is the monthly potential evapotranspiration (mm).

Step 2: The three-parameter log-logistic probability distribution function F(x) is used to normalize the water deficiency sequence D_i. The formula for the probability distribution function $F(x)$ is given below:

$$F(x)=\left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{s-2}$$

$$\alpha=\frac{(W_0-2W_1)\beta}{\Gamma(1+1/\beta)\Gamma(1-1/\beta)} \tag{s-3}$$

$$\beta=\frac{2W_1-2W_0}{6W_1-W_0-6W_2} \tag{s-4}$$

$$\gamma=W_0-\alpha\Gamma(1+\frac{1}{\beta})\Gamma(1-\frac{1}{\beta}) \tag{s-5}$$

where Γ is the factorial function, W_0, W_1, and W_2 are the probability-weighted moments of the water deficiency sequence D_i, and the computation formula is:

$$W_j=\frac{1}{n}\sum_{i=1}^{n}(1-F_i)^j D_i \tag{s-6}$$

$$F_i=\frac{i-0.35}{n} \tag{s-7}$$

where n is the number of months involved in the calculation.

Step 3: The SPEI is calculated by standardizing and transforming the cumulative probability density：

When the cumulative probability $P \le 0.5$:

$$P=F(x) \tag{s-8}$$

$$W=\sqrt{-2\ln(P)} \tag{s-9}$$

$$\mathrm{SPEI}=W-\frac{c_0+c_1W+c_2W^2}{1+d_1W+d_2W^2+d_3W^3} \tag{s-10}$$

When the cumulative probability $P > 0.5$:

$$P=1-F(x) \tag{s-11}$$

$$W=\sqrt{-2\ln(1-P)} \tag{s-12}$$

$$\mathrm{SPEI}=\frac{c_0+c_1W+c_2W^2}{1+d_1W+d_2W^2+d_3W^3}-W \tag{s-13}$$

where the constants are c_0=2.515517，c_1=0.802853，c_2=0.010328，d_1=1.432788，d_2=0.189269，d_3=0.001308.

S.3 Standardized Soil Moisture Index (SSMI)

This study employs the Standardized Soil Moisture Index (SSMI) to predict agricultural drought in the Loess Plateau of northern Shaanxi (Oertel et al., 2018; Khan et al., 2020), with a calculation process similar to that of the Standardized Precipitation Index (SPI). The calculations are as follows:

Step 1: Assuming that the soil moisture at a specific time scale is x, with the sequence adhering to the Gamma distribution, the cumulative probability distribution function of the soil moisture x is:

$$F(x)=\int_0^x \frac{1}{\beta^{\alpha}\Gamma(\alpha)}x^{\alpha-1}e^{\frac{-x}{\beta}}dx \tag{s-14}$$

$$\Gamma(\alpha)=\int_0^{\infty}x^{\alpha-1}e^{-x}dx \tag{s-15}$$

where $\Gamma(\alpha)$ is the gamma function, α and β are the shape and scale parameters, respectively, which can be estimated by the maximum likelihood method.

Step 2: When soil moisture is zero, the cumulative probability distribution function can be determined using the following formula:

$$F(x=0)=\frac{m}{n} \tag{s-16}$$

where m represents the number of samples with soil moisture of 0, and n represents the total number of samples.

Step 3: The SSMI index can be derived by normalizing the cumulative probability distribution function and applying the approximate solution calculation method. Here's the calculation formula:

$$\mathrm{SSMI}=S\frac{t-\left(c_2t+c_1\right)t+c_0}{\left[\left(d_3+d_2\right)t+d_1\right]t+1.0} \tag{s-17}$$

$$t=\sqrt{2\ln\left(F\right)} \tag{s-18}$$

When F>0.5, S=1; when F<0.5, S=-1. The values of c_0, c_1, c_2, d_1, d_2, and d_3 remain the same as before.

The drought classification is list in Table S1.

Table S1. Drought level classifications

	Extreme drought	Severe drought	Moderate drought	Mild drought	Normal
SPEI	(-∞, -2.0]	(-2.0, -1.5]	(-1.5, -1.0]	(-1.0, -0.5]	(-0.5, ∞]
SSMI	(-∞, -2.0]	(-2.0, -1.5]	(-1.5, -1.0]	(-1.0, -0.5]	(-0.5, ∞]

S.4 Results

Based on the above calculation methods, this study calculated the SPEI and SSMI at 1-month, 3-month, and 12-month time scales, as illustrated in the figure S2-S7.

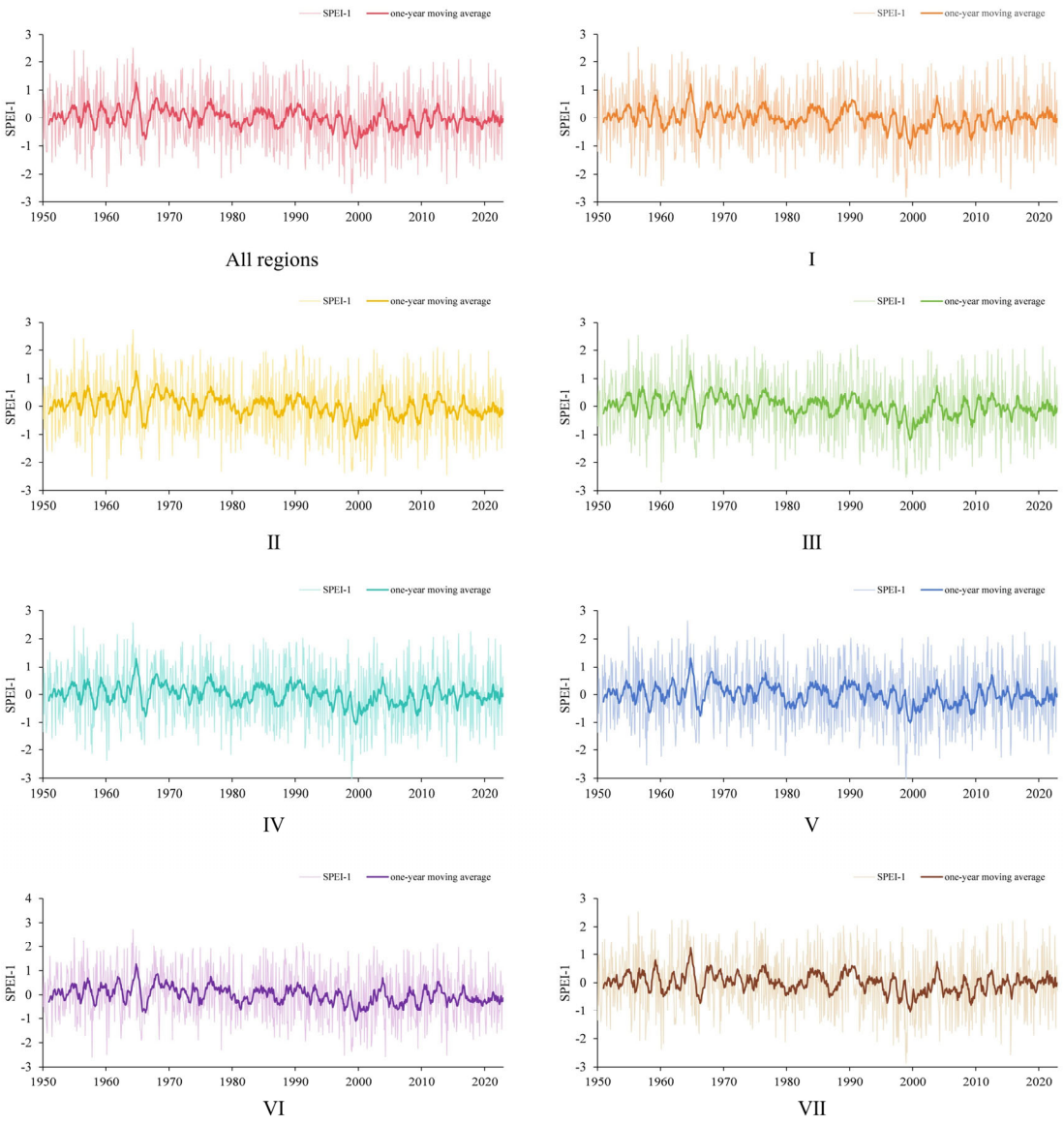


Figure S2 The calculation results of SPEI-1.

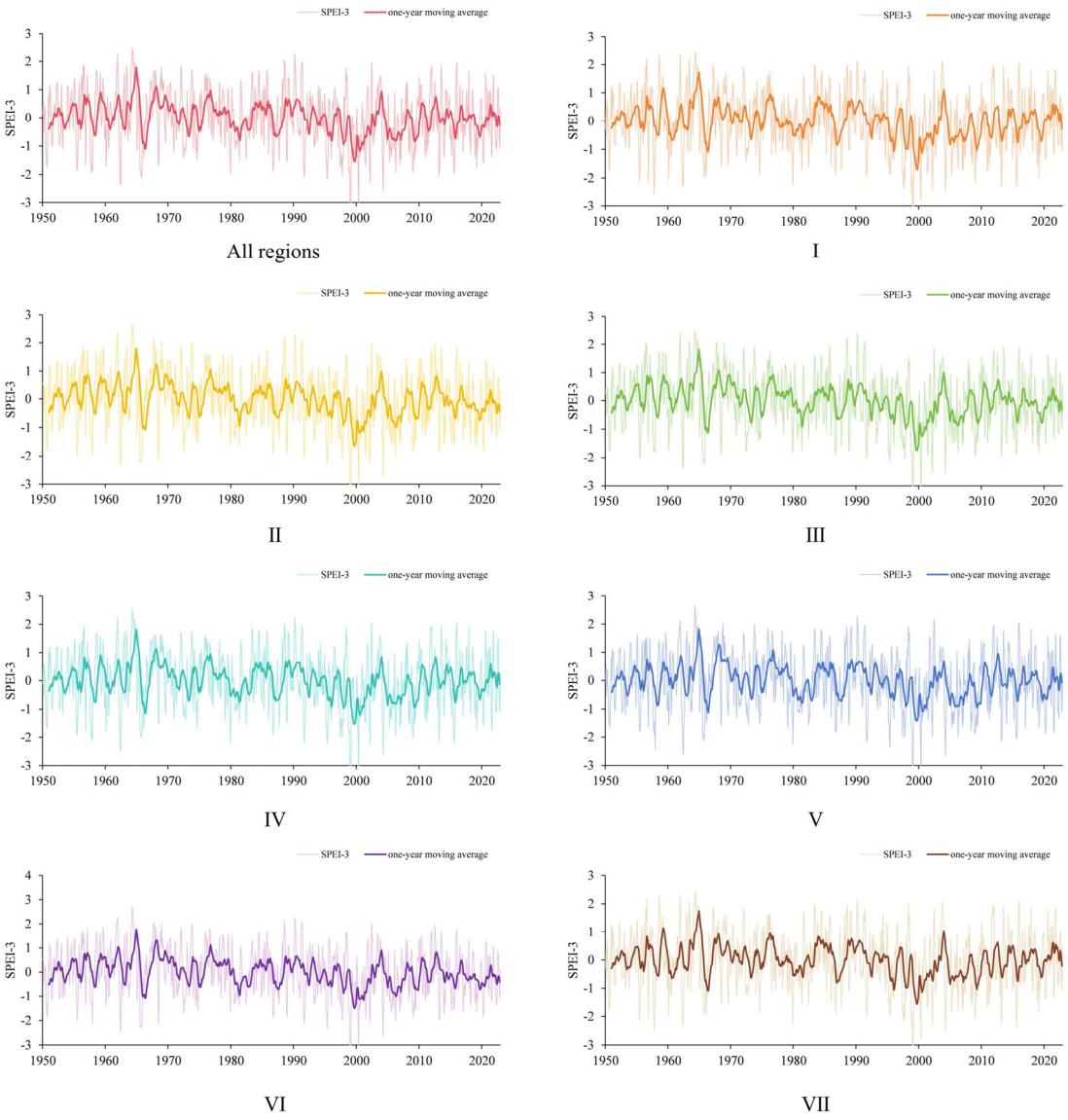


Figure S3 The calculation results of SPEI-3.

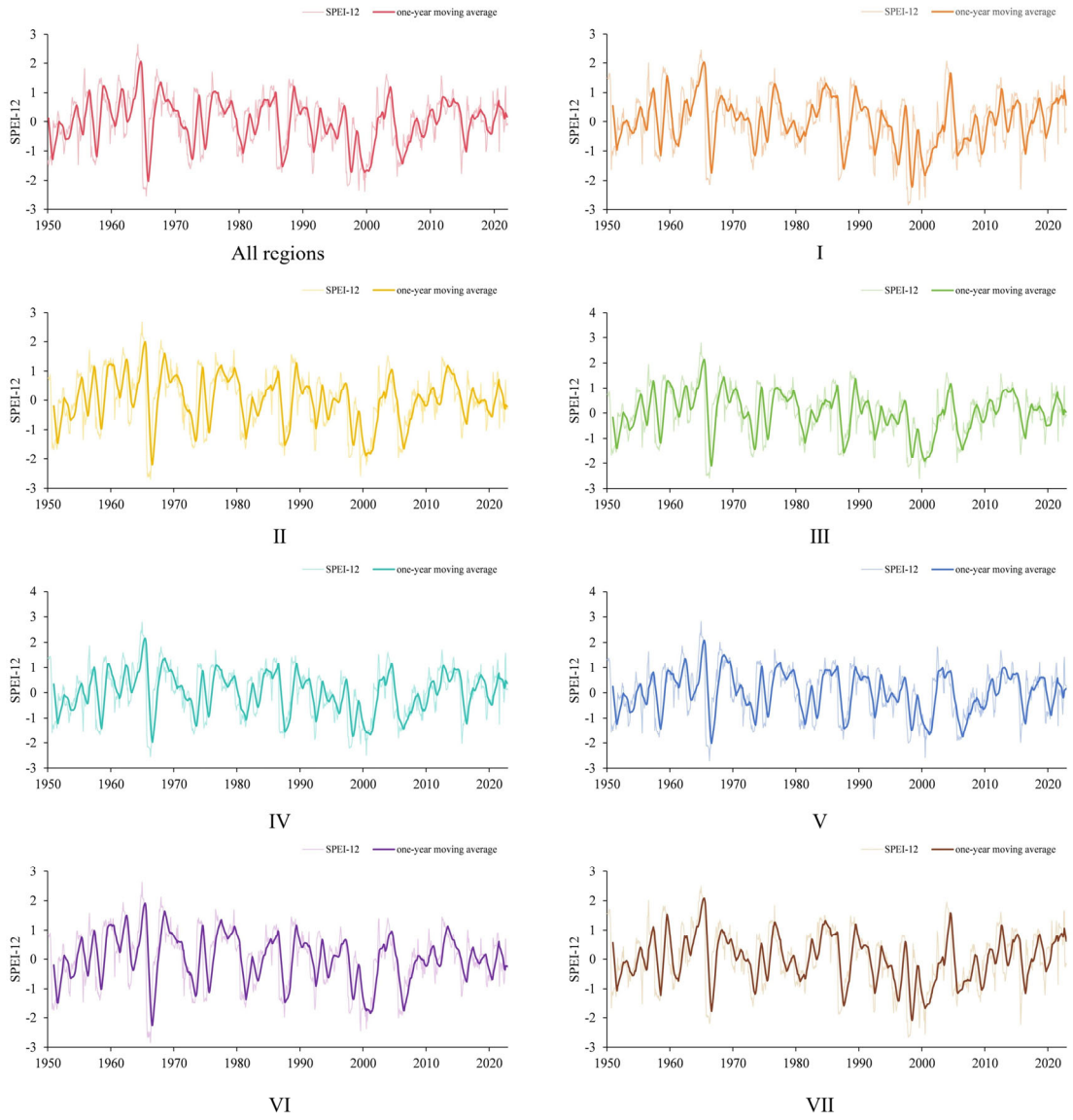


Figure S4 The calculation results of SPEI-12.

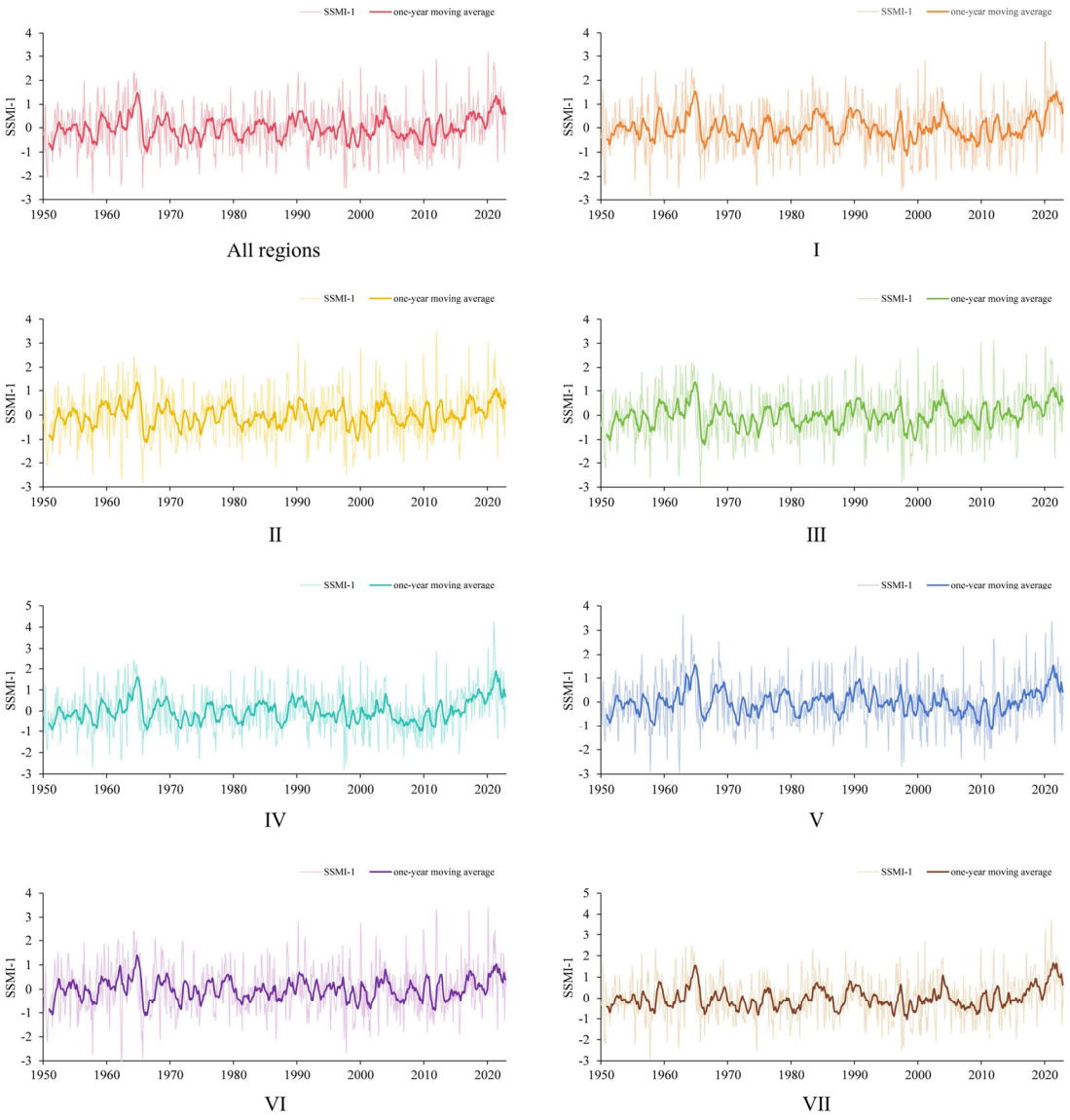


Figure S5 The calculation results of SSMI-1.

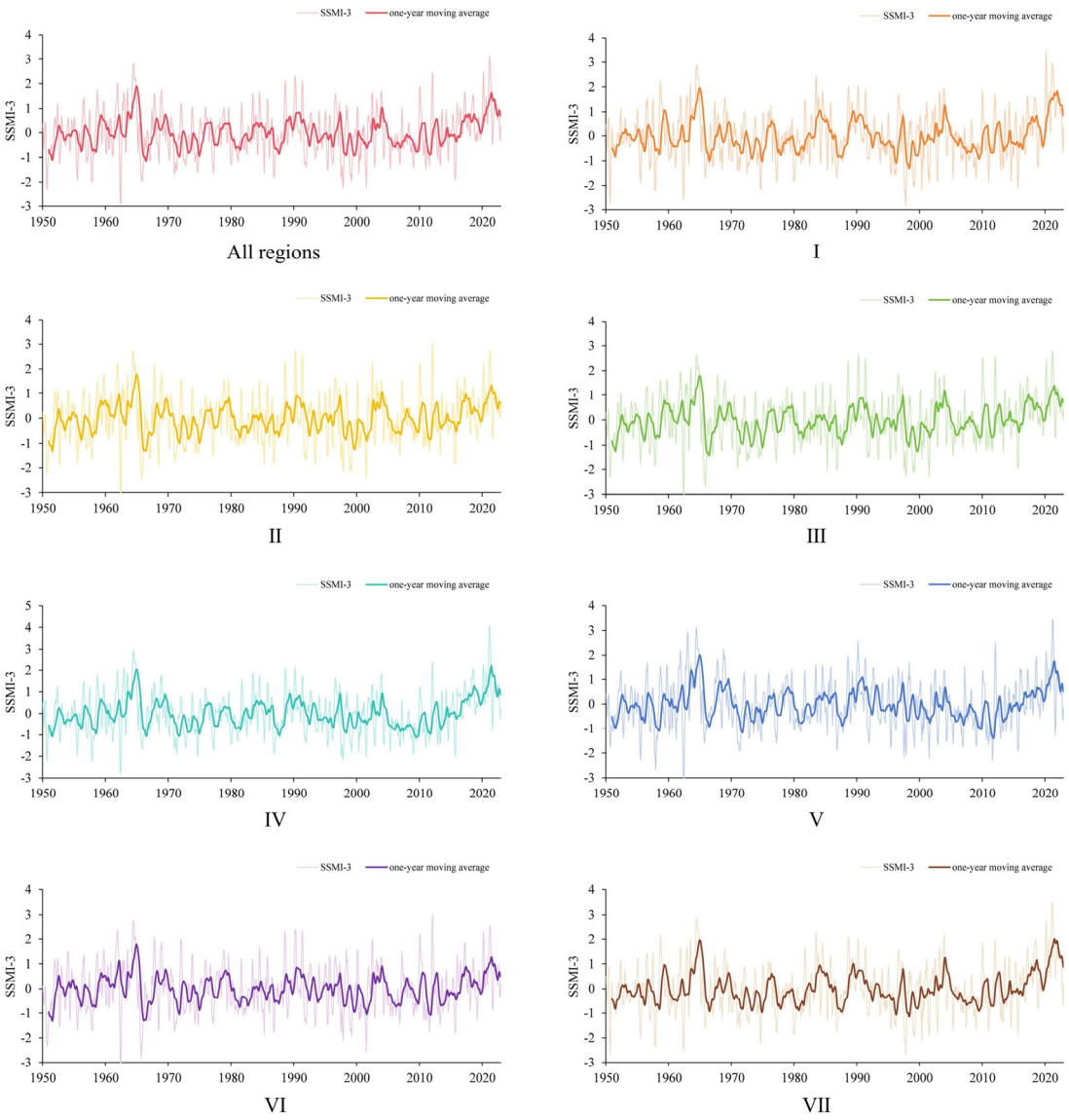


Figure S6 The calculation results of SSMI-3.

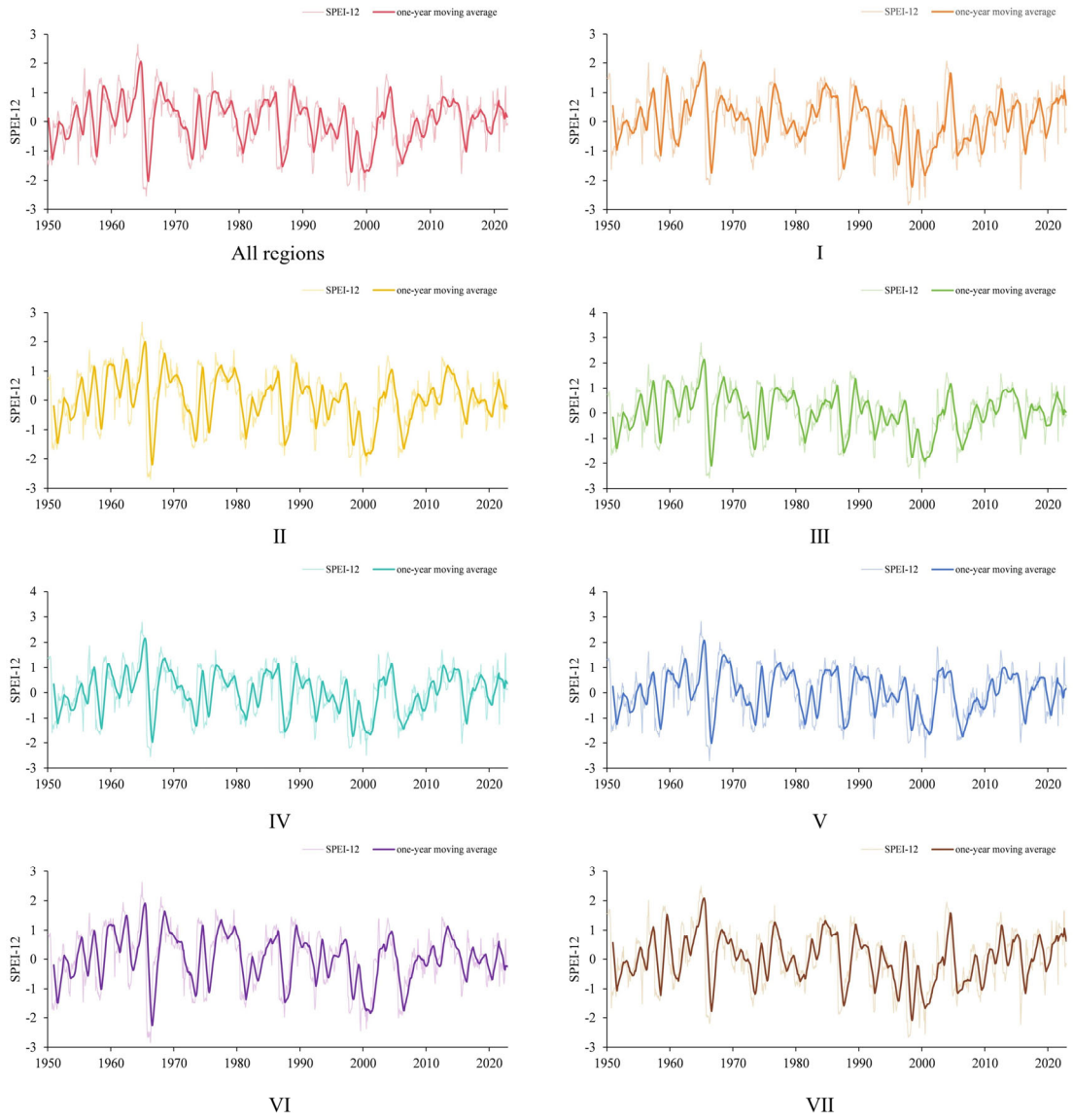


Figure S7 The calculation results of SSMI-12.

S.5 OPGD model driving factor q-value and its associated p-value

Table S2. OPGD model driving factor q-value and its associated p-value.

Variable	q-value	Sig
X_1	0.34	8.90E-10
X_2	0.07	6.14E-10
X_3	0.14	6.06E-10
X_4	0.30	6.79E-10
X_5	0.28	7.74E-10
X_6	0.01	7.65E-10
X_7	0.16	6.42E-10

X_8	0.01	2.33E-10
X_9	0.16	9.73E-10

Reference

1. Fowé, T.; Yonaba, R.; Mounirou, L.A.; Ouédraogo, E.; Ibrahim, B.; Niang, D.; Karambiri, H.; Yacouba, H. From meteorological to hydrological drought: A case study using standardized indices in the Nakanbe River Basin, Burkina Faso. *Nat. Hazards* **2023**, *119*, 1941–1965.