Drought and Flood Characteristics in the Farming-Pastoral Ecotone of Northern China Based on the Standardized Precipitation Index

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Abstract

The farming-pastoral ecotone of northern China (FPENC) provides an important ecological barrier which restrains the invasion of desert into Northwest China. Studying drought and flood characteristics in the FPENC can provide scientific support and practical basis for the protection of the FPENC. Based on monthly precipitation data from 115 meteorological stations, we determined the changes in climate and the temporal and spatial variations of drought and flood occurrence in the FPENC during 1960–2020 using the Standardized Precipitation Index (SPI), Morlet wavelet transform, and inverse distance weighted interpolation method. Annual precipitation in the FPENC showed a slightly increasing trend from 1960 to 2020, with an increasing rate of about 1.15 mm/a. The interannual SPI exhibited obvious fluctuations, showing an overall non-significant upward trend (increasing rate of 0.02/a). Therefore, the study area showed a wetting trend in recent years. Drought and flood disasters mainly occurred on an interannual change cycle of 2–6 and 9–17 a, respectively. In the future, a tendency towards drought can be expected in the FPENC. The temporal and spatial distribution of drought and flood differed in the northwestern, northern, and northeastern segments of the FPENC, and most of the drought and flood disasters occurred in local areas. Severe and extreme drought disasters were concentrated in the northwestern and northeastern segments, and severe and extreme flood disasters were mainly in the northeastern segment. Drought was most frequent in the northwestern segment, the central part of the northeastern segment, and the northern part of the northern segment. Flood was most frequent in the western part of the northwestern segment, the eastern part of the northeastern segment, and the eastern and western parts of the northern segment. The accurate evaluation of the degrees of drought and flood disasters in the FPENC will provide scientific basis for the regional climate study and crit-

ical information on which to base decisions regarding environmental protection and socio-economic development in this region.

Full Text

Drought and Flood Characteristics in the Farming-Pastoral Ecotone of Northern China Based on the Standardized Precipitation Index

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Abstract

The farming-pastoral ecotone of northern China (FPENC) constitutes a critical ecological barrier that restrains desert encroachment into Northwest China. Investigating drought and flood characteristics in this region provides essential scientific support and a practical foundation for its ecological protection. Based on monthly precipitation data from 115 meteorological stations, we analyzed climate changes and the spatiotemporal variations of drought and flood occurrence in the FPENC during 1960–2020 using the Standardized Precipitation Index (SPI), Morlet wavelet transform, and inverse distance weighted interpolation. Annual precipitation exhibited a slight increasing trend from 1960 to 2020, with a rate of approximately 1.15 mm/a. Interannual SPI values showed pronounced fluctuations with an overall non-significant upward trend (increasing rate of 0.02/a), indicating a recent wetting tendency in the study area. Drought and flood disasters primarily occurred on interannual cycles of 2–6 years and 9–17 years, respectively, with a future drought tendency expected for the FPENC. The temporal and spatial distribution of drought and flood differed across the northwestern, northern, and northeastern segments, with most disasters occurring locally. Severe and extreme droughts concentrated in the northwestern and northeastern segments, while severe and extreme floods occurred mainly in the northeastern segment. Drought was most frequent in the northwestern segment, the central part of the northeastern segment, and the northern part of the northern segment. Flood was most frequent in the western part of the northwestern segment, the eastern part of the northeastern segment, and the eastern and western parts of the northern segment. This accurate evaluation of drought and flood disaster severity provides a scientific basis for regional climate studies and critical information to support environmental protection and socioeconomic development decisions in the FPENC.

Keywords: farming-pastoral ecotone of northern China (FPENC); Standardized Precipitation Index (SPI); drought; flood; Morlet wavelet transform

1 Introduction

Accelerating global warming has significantly altered the intensity and frequency of extreme climate events in China, leading to frequent meteorological disasters such as drought and flood [?, ?]. Research demonstrates that drought and flood disasters are the most frequently occurring meteorological hazards, affecting the largest areas and exerting the greatest impact on crop production, with economic losses far exceeding those from other disasters [?, ?]. Numerous drought and flood evaluation indices are currently in wide use, including the Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), and Standardized Precipitation Evapotranspiration Index (SPEI) [?, ?]. Selecting the most appropriate index is crucial for effective regional drought and flood prevention and control.

Extensive research has investigated drought and flood characteristics and impacts using various methodologies [?, ?, ?, ?, ?, ?, ?, ?]. The SPI is the most widely applied index because its values across different time-scales can characterize different types of drought and flood events, making it applicable to all climate conditions in practice [?]. Moreover, SPI calculation is straightforward, requiring only precipitation data and fewer inputs than other indices. For instance, [?] calculated multi-scale SPI values using precipitation data from ten meteorological stations in Heilongjiang Province from 1953–2015, demonstrating that precipitation is the primary factor influencing drought. [?] investigated the spatiotemporal evolution of meteorological drought in China' s Poyang Lake Basin using SPI. [?] employed SPI to analyze extreme drought and flood disasters at 42 meteorological stations in northwestern Algeria' s Macta Basin during 1970–2011. [?] examined temporal variation, periodic characteristics, and spatial differentiation of drought and flood in Northeast Guangdong Province using SPI combined with wavelet analysis and correlation analysis.

The farming-pastoral ecotone of northern China (FPENC) lies in the transition zone between semi-humid agricultural areas and arid/semi-arid pastoral areas in northern China [?]. Agricultural systems vary significantly across the FPENC [?], and the region has developed a fragile ecosystem due to its sensitivity to climate change and human activity impacts. Therefore, studying drought and flood characteristics based on climate data is essential for agricultural development, livestock structure adjustment, and sustainable national economic development in China. While methods for studying regional drought and flood characteristics have matured and SPI offers a widely applicable approach, most studies have been conducted on short time-scales, with limited research focusing on the important agricultural and pastoral areas of the FPENC.

This study employed SPI, inverse distance weighted interpolation, and Morlet wavelet transform analysis to investigate the temporal characteristics, periodic features, and spatial patterns of drought and flood disasters in the FPENC on a long time-scale. Specifically, our objectives were to: (1) examine temporal variation and cyclical fluctuation characteristics of drought and flood in the FPENC; (2) reveal spatial distribution characteristics of drought and flood; and (3) explore spatial variation characteristics of drought and flood frequency. These results will establish a foundation for understanding climate change and spatiotemporal drought/flood variations while providing scientific support and practical guidance for environmental protection, policy development, and regional sustainable management in the FPENC.

2.1 Study Area

The boundaries of the FPENC vary according to specific study requirements, though most research shares a broadly common definition of its core area. This study focuses on the region between 34°49 -48°32 N and 100°57 -124°43 E [**?**] (Fig. 1), covering approximately 0.726$×10^{6}$ km^{2}. The area extends from southwestern Heilongjiang Province in the north to eastern Qinghai Province in the south, spanning ten provinces and autonomous regions in northwestern, northern, and northeastern China (Heilongjiang, Liaoning, Jilin, Hebei, Shanxi, Shaanxi, Gansu, Qinghai, Inner Mongolia Autonomous Region, and Ningxia Hui Autonomous Region). Situated in the transition zone between semi-humid continental monsoon climate and typical dry continental climate, the region has an average annual temperature of 2°C–8°C and annual precipitation of 250–500 mm. Elevation increases from northwest to southeast, with farmland and grassland as the primary land use types [**?**, **?**]. The northern FPENC serves as an important ecological barrier preventing desert invasion into Northwest China; however, variable climatic conditions and inappropriate farming practices have caused severe soil erosion and frequent natural disasters.

2.2 Data Sources and Processing

Monthly precipitation data for the FPENC from 1960–2020 were obtained from the China Meteorological Data Network (http://data.cma.cn/site/index.html). The distribution of meteorological stations is shown in Figure 1. Data from each station were sorted to ensure accuracy, and precipitation records from stations within and around the study area were strictly screened to eliminate repositioned stations during this period. Finally, data from 115 meteorological stations were retained. To ensure data integrity and continuity, linear interpolation was performed to estimate small numbers of missing values based on precipitation data from adjacent months at the same station.

2.3.1 Standardized Precipitation Index (SPI)

Precipitation data distributions are typically skewed rather than normal, with the Gamma (Γ) distribution probability commonly used to describe precipitation changes. SPI calculates the Γ distribution probability of precipitation over a specific period, performs normal standardization on the skewed probability distribution, and uses the standardized cumulative precipitation frequency distribution to determine drought or flood grade [?]. The calculation steps follow [?].

Assuming precipitation during a certain period is a random variable x, the Γ distribution probability density function f(x) is:

$$f(x) = \frac{1}{\beta^\gamma \Gamma(\gamma)} x^{\gamma-1} e^{-x/\beta}, \quad x > 0$$

where e is the natural logarithm; β and γ are scale and shape parameters, respectively (β>0 and γ>0), obtained through maximum likelihood estimation:

$$\hat{\gamma} = \frac{1 + \sqrt{1 + 4A/3}}{4A}, \quad \hat{\beta} = \frac{\bar{x}}{\hat{\gamma}}, \quad A = \ln(\bar{x}) - \frac{1}{n}\sum_{i=1}^{n} \ln(x_i)$$

where $\hat{\beta}$ and $\hat{\gamma}$ are the estimated scale and shape parameters ($\hat{\beta} > 0$ and $\hat{\gamma} > 0$); A is an intermediate parameter for calculating γ; x_i is the precipitation data sample (mm); and $\bar{x}$ is the climate average of precipitation (mm). After determining the probability density function parameters, the probability that random variable x is less than precipitation x_0 in a given year can be calculated as:

$$F = \int_0^{x_0} f(x)dx$$

where F is the event probability. The approximate probability estimate is obtained by numerical integration after substituting the expression for f(x).

The event probability when precipitation equals 0.00 mm is estimated by:

$$F_0 = \frac{m}{n}$$

where m is the number of samples with precipitation of 0.00 mm, and n is the total number of samples.

For normal standardization, probability values from the above equations are substituted into the standardized normal distribution function to obtain SPI through the approximate solution:

$$Z = SPI = S\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right)$$

where t is the process parameter during calculation, $t = (\ln(1/F^2))^{1/2}$; and S is the positive/negative coefficient of probability density (S=1 if F>0.5; S=-1 if F$ $0.5). In the equation, c_0, c_1, c_2, d_1, d_2, and d_3 are constants with values of 2.515517, 0.802853, 0.010328, 1.432788, 0.189269, and 0.001308, respectively.

Based on this method, SPI values at 3-month (SPI-3) and 12-month (SPI-12) time-scales were calculated to reflect seasonal and interannual drought and flood characteristics in the FPENC. According to the national standard for meteorological drought classification (GB/T 20481-2006) [?], SPI can be divided into different drought and flood grades (Table 1).

Table 1. Classification standard of drought and flood grades based on the Standardized Precipitation Index (SPI)

<table>
<tr><th>Drought/flood grade</th><th>SPI range</th></tr>
<tr><td>Extreme flood</td><td>SPI$ 2.0||Severeflood|1.5 SPI < 2.0||Moderateflood|1.0 SPI < 1.5||Lightflood|0.5 SPI < 1.0||Normal|–0.5 < SPI < 0.5||Lightdrought|–1.0 < SPI –0.5||Moderatedrought|–1.5 < SPI –1.0||Severedrought|–2.0 < SPI –1.5||Extremedrought|SPI $-2.0</td></tr>
</table>

2.3.2 Wavelet Transform

One-dimensional complex continuous wavelet analysis extracts various change periods within a time series, fully reflecting SPI value variations across different time-scales and estimating drought and flood trend directions in the FPENC. The wavelet basis is defined as [?]:

$$\varphi(t) = \pi^{-1/4}(e^{i2\pi F_c t})e^{-t^2/(2F_b)}$$

where $\varphi(t)$ is the wavelet function; F_b is the bandwidth parameter; e is the natural logarithm; i is the imaginary number; F_c is the central frequency; and t is time (years). Sub-wavelets are generated by stretching and translating the wavelet basis:

$$\varphi_{a,b}(t) = \frac{1}{\sqrt{a}}\varphi\left(\frac{t-b}{a}\right)$$

where $\varphi_{a,b}(t)$ is the sub-wavelet function; a is the scalability factor, and b is the time shift factor.

2.3.3 Drought (or Flood) Station Rate

The drought (or flood) station rate represents the percentage of weather stations recording drought (or flood) events relative to the total stations in the study area, assessing the extent of influence. It is calculated as:

$$P_i = \frac{m_i}{M} \times 100\%$$

where P_i is the drought (or flood) station rate (%); m_i is the number of stations recording drought (or flood) events in the ith year; and M is the total number of stations (115). Classification criteria for drought (or flood) extent are: $P_i \geq 70\%$ indicates whole-region events; $50\% \leq P_i < 70\%$ indicates regional events; $30\% \leq P_i < 50\%$ indicates partial-area events; $10\% \leq P_i < 30\%$ indicates local events; and $P_i < 10\%$ indicates no obvious drought (or flood) [?].

2.3.4 Drought (or Flood) Frequency

Drought (or flood) frequency evaluates the occurrence frequency at individual stations in the FPENC [?]:

$$P_j = \frac{n_j}{N} \times 100\%$$

where P_j is the drought (or flood) frequency at the jth station (%); n_j is the number of years with a specific drought (or flood) level recorded at the jth station; and N is the total study period (61 years).

2.3.5 Inverse Distance Weighted Interpolation

Inverse distance weighted interpolation assumes each measurement point has local influence that decreases with distance. The expression is [?]:

$$\hat{\mu}(x) = \sum_{i=1}^{n} \omega_i(s) y_i$$

where $\hat{\mu}(x)$ is the interpolated value; $\omega_i(s)$ is the distance weighting function (or the nth power reciprocal of distance, where n is a positive integer); and y_i is the sample point value. The weights must satisfy the normalization condition:

$$\sum_{i=1}^{n} \omega_i(s) = 1$$

After analyzing and correcting the original data, the uniform point distribution and adequate data density were found suitable for calculating drought (or flood) grade changes, leading to the selection of inverse distance weighted interpolation for this study.

3.1 Characteristics of Precipitation Change

Annual precipitation in the FPENC first decreased then increased during 1960-2020 (Fig. 2). The average annual precipitation was 445.40 mm, showing only a slight, insignificant increasing trend overall (1.15 mm/a). Precipitation fluctuated dramatically around 1964, peaking at 592.99 mm in 1964 and reaching its lowest value of 346.51 mm in 1965—a difference of 246.48 mm. The 1960s experienced relatively high precipitation with the most extensive fluctuation range and high variability. From the 1970s to 1990s, annual precipitation fluctuated around the mean with relative stability. Since 2000, precipitation has shown an apparent upward trend, with values during 2015-2020 exceeding the overall linear trend for 1960-2020.

3.2 Temporal Variation Characteristics of Drought and Flood Based on the SPI

SPI values at 3-month and 12-month time-scales (Fig. 3) revealed that short time-scales (3 months) exhibited high variability in dry-wet cycles, while large time-scales (12 months) showed significantly lower cycle frequency.

The 12-month SPI series (Fig. 3b) indicated significant interannual fluctuations during 1960-2020, with an overall non-significant upward trend ($P>0.05$; increasing rate of 0.02/a). The 5-year moving average revealed prominent stage characteristics with obvious turning points in 1972 (downward), 1979 (upward), 1983 (downward), 1988 (upward), and 2001 (downward). Based on Table 1, interannual SPI values were divided into drought/flood grades, revealing a noticeable wetting trend in recent years. Sixteen droughts occurred over the 61-year period, averaging one drought every 3.81 years. Drought periods concentrated in 1962-1972, 1980-1982, and 1997-2009, with severe droughts in 1965, 1972, 1982, 1997, 1999, 2000, and 2001. Flood periods concentrated in 1961-1967, 1985-2003, and 2012-2020, reaching severe flood levels in 1964 and 2012—consistent with annual precipitation changes. The interannual SPI showed a downward trend from 1960-2012, with disastrous drought frequent during 2000-2012, aligning with [**?**].

3.3 Fluctuation Characteristics of Drought and Flood Cycles Based on the SPI

The isoline of the real part of wavelet coefficients (Fig. 4a) reveals periodic SPI changes across time-scales. Red (blue) indicates positive (negative) real parts, representing considerable (slight) precipitation; deeper colors indicate greater flood (drought) severity. The SPI change process showed two periodic time-scale variations: 2-6 years and 9-17 years. The central scale of 9-17 years was 13 years, with a noticeable positive-negative closed center in the coefficient contour map, indicating a 13-year periodic oscillation interval. The 2-6 year variation remained relatively stable during 1960-1979 and 1984-2020, with weak cycle changes during 1979–1984. The 9–17 year scale was relatively stable during 1997–2017, with less remarkable cycles before 1997 and after 2017.

The wavelet variance diagram (Fig. 4b) reflects wave energy distribution of the SPI time series with annual scale, determining the main change period. Three apparent peaks corresponded to time-scales of 13, 7, and 4 years, indicating these cycles significantly influenced spatiotemporal drought and flood changes over 61 years. The maximum peak at 13 years represented the strongest cyclical oscillation, with alternating positive-negative SPI cycles exerting the most decisive impact on FPENC drought and flood—the primary fluctuation cycle. The 4-year scale corresponded to the second peak (second main period), while the 7-year scale reached the third peak (third main period). These three cycles controlled drought and flood variation throughout the study period. Approximately six drought-flood alternations occurred within 13 years, with an average cycle of nearly 10 years. Twenty alternations occurred within 4 years (average ~3-year cycle), and about 12 alternations within 7 years (average ~5-year cycle). Analysis indicates negative (blue) real parts of wavelet coefficients at time-scales under 3 years after 2020, predicting a future drought tendency in the FPENC.

3.4.1 Extents of Drought and Flood

The drought (or flood) station rate reflects drought/flood extent evaluation in the FPENC (Fig. 5). Drought station percentages fluctuated between 6.09% and 73.91% over 61 years, averaging 31.36%. Twenty-six years exceeded this average, while 35 years were below it. The linear trend (red line in Fig. 5) showed a downward trend (decreasing rate of ~0.11/a), indicating reduced drought-affected area in recent decades. The maximum drought extent occurred in 1972 (73.91% of stations). Flood station percentages fluctuated between 0.86% and 76.52%, averaging 31.20%. The flood extent showed an overall upward trend (increasing rate of ~0.08/a), indicating increased flood-affected area.

Table 2 summarizes drought and flood occurrence frequencies. Whole-region drought occurred only once (1972), with most droughts localized. Regional drought persisted for three consecutive years around 2000. During 2000–2009, drought affected the FPENC extensively, with five regional droughts occurring on average once every two years. Thereafter, localized drought dominated, with eight events from 2010–2020 (approximately one per year). Most floods occurred locally or partially, with whole-region flood occurring only once in 1964.

3.4.2 Spatial Distribution Characteristics of Drought and Flood Grades

Figure 6 illustrates spatial drought and flood grade distributions in the FPENC. In 1960 (Fig. 6a), severe drought and flood were rare. Dry regions appeared in the eastern northwestern segment, central northern segment, and the northern-northeastern junction, mostly experiencing light drought, with moderate and severe drought concentrated in Gansu Province and Inner Mongolia Autonomous

Region. Flooded areas focused on the northeastern segment' s northeast. In 1970 (Fig. 6b), drought and flood disasters were relatively few, with most regions unaffected. Flood concentrated in Gansu Province (mainly light), while light drought occurred mostly in the northern segment and moderate drought in Heilongjiang and Shaanxi provinces.

In 1980 (Fig. 6c), drought affected most regions except Heilongjiang Province. Moderate and severe drought concentrated in the northern northwestern segment, eastern northern segment, and western northeastern segment. In 1990 (Fig. 6d), flood occurred more frequently across the study area, concentrating in the central northwestern segment and most regions from the northern to northeastern segments (mainly light or moderate), while drought appeared only in Qinghai Province' s northwest. In 2000 (Fig. 6e), the entire study area was normal except for partial drought: light drought concentrated in the northwestern segment and eastern northern segment, while moderate and severe drought occurred in the northeastern part of the northwestern segment, eastern northern segment, and most of the northeastern segment (except Jilin Province).

In 2010 (Fig. 6f), most areas exhibited normal conditions. Drought occurred mainly in Gansu Province (mostly light), while flood concentrated in Hebei and Liaoning provinces. In 2020 (Fig. 6g), drought was rare, occurring primarily in southwestern Liaoning Province. Light flood dominated the northwestern and northern segments, most notably in southern Gansu Province. Most northern segment regions experienced light or moderate flood, while flood degree in the northeastern segment increased from west to east.

3.5 Spatial Variations of Drought and Flood Frequencies Based on the SPI

Total drought frequency (Fig. 7a) was relatively high (33%-42%) in most of Gansu Province and Ningxia Hui Autonomous Region (northwestern segment) and in Liaoning and Heilongjiang provinces (northeastern segment). Frequency was lower (24%-33%) in Qinghai and Shaanxi provinces (northwestern and northern segments), except in parts of Hebei Province and most of the northeastern segment. Light drought frequency (Fig. 7b) was lower (13%-28%) in most of the northwestern segment, eastern northern segment, and Heilongjiang and Liaoning provinces, while low frequency (4%-13%) occurred in central northern segment and southeastern Inner Mongolia Autonomous Region and Jilin Province.

Moderate drought frequency (Fig. 7c) was higher in the eastern northwestern segment (8%-22%) and much lower in the western part (3%-8%). In the northern segment, low frequency concentrated in Shanxi and Hebei provinces, while other regions showed high frequency. In the northeastern segment, high frequency concentrated in Liaoning and Heilongjiang provinces and adjacent Inner Mongolia regions. Severe drought frequency (Fig. 7d) was generally below 10%, with higher values (3%-10%) in Qinghai and Gansu provinces (western northwestern segment), Shanxi and Hebei provinces (central northern segment), and most of the northeastern segment (except Jilin). Extreme drought frequency (Fig. 7e) remained below 7%, with relatively high values (1%-7%) in Shaanxi Province (northwestern segment), most of the northern segment, and the eastern northeastern segment.

Flood frequency was relatively high (30%-37%) in most of Qinghai Province (northwestern segment), Inner Mongolia Autonomous Region and Hebei Province (northern segment), and Liaoning and Heilongjiang provinces (northeastern segment) (Fig. 7f). Other regions ranged 22%-30%. Light flood frequency (Fig. 7g) was relatively high (15%-24%) in Qinghai and Gansu provinces (northwestern segment) and the northern segment (except parts of Shanxi), but low (4%-15%) in Ningxia Hui Autonomous Region, Shaanxi Province, and most of the northeastern segment.

Moderate flood frequency (Fig. 7h) was low (1%-10%) in Qinghai Province and the western northern segment, while high-frequency regions in the northeastern segment concentrated in Inner Mongolia Autonomous Region. Severe flood frequency (Fig. 7i) remained below 10%, with higher values (5%-9%) in eastern Gansu Province, the western northern segment, and most of the northeastern segment. Extreme flood frequency (Fig. 7j) was below 7%, with relatively high values (1%-6%) in most of the northwestern segment, western northern segment, and Inner Mongolia Autonomous Region in the northeastern segment, while other regions remained below 1%.

4.1 Applicability of SPI Analysis

Precipitation is readily available in basic climatic data and varies across temporal and spatial scales, playing an essential role in predicting seasonal and interannual regional climate [?]. Numerous indices evaluate drought and flood disasters, including SPI, Z-index, PDSI, and SPEI. SPI assumes regional precipitation follows a skewed probability distribution function, offering three key advantages: (1) applicability across different time-scales (1, 3, 12 months); (2) ability to reflect drought and flood severity across periods and regions; and (3) relatively simple calculation requiring minimal data. Consequently, SPI is widely used in drought and flood monitoring and climate assessment [?, ?, ?, ?, ?].

This study combined SPI with GIS spatial interpolation to analyze drought and flood characteristics and spatiotemporal changes in the FPENC over 61 years. Results showed the interannual SPI followed a downtrend before 2012, indicating noticeable aridity, then an upward trend after 2012, showing humidification. Disastrous drought occurred frequently in the 2010s. Over 61 years, drought was frequent in the northwestern FPENC, with more serious drought in northern and northeastern segments—findings consistent with published literature [?, ?].

4.2 Spatio-Temporal Variations of Drought and Flood Based on SPI

This paper' s spatiotemporal SPI variations in the FPENC require literature data supplementation. Further analysis of SPI variation characteristics and verification against observed drought and flood conditions is necessary to accurately reflect actual regional characteristics. The study revealed that in 1960, drought occurred mainly in the eastern northwestern segment, central northern segment, and northern-northeastern junction (Fig. 6a–e). In 1970, fewer drought and flood events occurred, with light drought frequent in the northern segment. In 1980, drought affected all provinces except Heilongjiang, with moderate and severe drought concentrated in the northern northwestern segment, eastern northern segment, and western northeastern segment. In 1990, flood was more frequent across the study area, concentrating in the middle northwestern segment and most regions from the northern to northeastern segments. In 2000, the northeastern part of the northwestern segment, eastern northern segment, and northeastern segment (except most of Jilin Province) suffered moderate and severe drought.

Historical drought and flood records from the *China Meteorological Disasters Statistics (Comprehensive Volume)* [**?**] show: serious drought affected northern China in winter-spring 1960, with severe drought throughout Gansu Province and extensive, prolonged drought in Inner Mongolia. Autumn-early winter 1970 drought in North China resulted from minimal rainfall and snowfall. In 1980, prolonged severe drought affected wide areas of Gansu Province; from autumn 1979 to August 1980, Ningxia Hui Autonomous Region received no rainfall, and drought was most serious in Hebei Province, with major rivers maintaining low flow while others dried up. In Inner Mongolia' s farming-pastoral areas, long-term low rainfall caused groundwater levels to drop over 1.0 m. Liaoning Province experienced little post-summer rainfall, causing drought in most regions. In 1990, rainstorms and floods affected some regions, with heavy rainfall in the eastern northwestern segment, most of the northern segment, and southern northeastern segment. Spring-summer 2000 saw serious drought in the northern segment, with low precipitation north of the Yangtze River causing widespread spring drought across all segments and even lower summer precipitation in the northern segment, eastern northwestern segment, and northeastern segment, resulting in severe spring-summer drought in some areas.

Comparison with [**?**] reveals slight differences between SPI-based analysis and actual conditions in some regions, but most results were consistent with historical records. Therefore, SPI provides robust characterization of drought and flood characteristics in the FPENC.

5 Conclusions

Analysis of temporal characteristics, periodic features, and spatial patterns of drought and flood in the FPENC from 1960–2020 yields the following conclusions: Annual precipitation first decreased then increased over 61 years. Overall, interannual SPI showed a slight upward trend (P>0.05), with a recent wetting trend consistent with annual precipitation changes. Morlet wavelet transform revealed periodic variations of 2–6 and 9–17 years, with alternating drought and flood disasters. After 2020, the FPENC will likely experience drought. Over 61 years, drought extent has reduced. Whole-region drought and flood occurred only once each, though regional events were frequent. Temporal and spatial distributions of drought/flood degree and frequency showed regional differences. This study provides a theoretical basis for drought and flood disaster management and future policy-making in the FPENC.

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Note: Figure translations are in progress. See original paper for figures.