Article

Analysis of Drought Characteristics and Its Effects on Crop Yield in Xinjiang in Recent 60 Years

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Abstract: With global warming, the frequency of drought in China is gradually increasing. The study of drought characteristics and its impact on crop yield is of great significance to ecological construction and food security. Based on the SPEI index in Xinjiang from 1961 to 2020, the changing characteristics of drought and their responses to meteorological yield of three kinds of crops (cotton, wheat and corn) were analyzed. The results revealed that the SPEI in Xinjiang exhibited a decreasing trend. Drought occurred less during 1961–1996 and mainly occurred during 1997–2020. The annual variation trend of SPEI decreased regionally, and the arid trend increased from northwest to southeast. The seasonal variation in SPEI displayed an increasing trend only in winter, but a decreasing trend in spring, summer and autumn. The decreasing trend of the SPEI index in spring accounted for 90.91%, mainly distributed in the central and eastern part of Xinjiang; the decreasing trend in summer accounted for 81.82%, mainly located in the eastern part of Xinjiang; the decreasing trend in autumn accounted for 84.85%, mainly located in the south and central and eastern part of Xinjiang; the decreasing trend in winter accounted for only 33.33%, mainly located in the southwest, central and eastern part of Xinjiang; the per unit area yield of the three kinds of crops showed a significant increasing trend (p < 0.01). The meteorological yield of cotton showed an increasing trend, while that of wheat and corn showed a decreasing trend. Correlation analysis of climatic yield and SPEI, and regression analysis of standardized climatic yield residuals and SPEI in different seasons revealed that drought in spring and autumn had the greatest effect on the meteorological yield of cotton, while drought in spring and summer had the greatest effect on the meteorological yield of wheat and cotton.

Keywords: drought characteristics; crop yield; Xinjiang; SPEI index; climate changes

1. Introduction

Drought is an extreme climate event characterized by a long period of reduced precipitation over months to years [1]. In recent years, drought, a complex natural disaster, has been occurring with increasing frequency throughout the country, and its duration has been gradually lengthening, causing serious impacts to the environment, society and economy [2]. Low precipitation and high evaporation are the direct causes of drought. The change in temperature has a significant impact on the change in precipitation and evaporation. In addition, the abnormal atmospheric circulation and increased rainstorms and soil erosion can all cause drought [3–6]. China is a big agricultural country, and agriculture is the foundation of its national economy, while drought is the main restrictive factor affecting the agricultural economy [7]. According to statistics, drought accounts for the largest proportion of natural disasters in China on average every year, accounting for 55% of the total affected area. In the recent 30 years, it has shown an expanding trend from north to south and from west to east [8]. Therefore, the study of drought is particularly important.

The study of drought requires a fixed quantitative description of indicators in order to facilitate its dynamic monitoring. The drought index is the main tool used to study drought. At present, commonly used calculation methods of drought indicators include
the Palmer Drought Severity Index (PDSI) [9], Standardized Precipitation Index, SPI [10] and Standardized Precipitation Evapotranspiration Index (SPEI) [11]. PDSI, proposed by Palmer in 1965 [12], is a drought index based on the principle of surface water balance. However, its calculation process is complex and its definition of drought is highly subjective, therefore it is not suitable for large-scale use [13]. The Standardized Precipitation Index (SPI) was proposed by Mckee et al., (1993) [14], and this method is simple, feasible and can be presented at multiple scales, and only precipitation data are needed for calculation. However, under the global warming environment, temperature has also become an important basis for drought indexes. Based on this, Vicente-Serranotal et al., (2010) not only considered the advantages of flexible SPI time scale but also the advantages of PDSI water balance, they constructed the standardized precipitation Index (SPEI) [15], which has good application prospects [16]. Xinjiang is a typical arid and semi-arid region, and the change in its drought conditions has attracted more and more attention [17]. Although many scholars have proposed the trend of climate transition from warm and dry to warm and wet in Xinjiang [18–20], the areas affected by drought are expanding year by year, and the losses caused by drought disasters in Xinjiang are increasing [21]. The agricultural production system, established for thousands of years, has inherent historical origins and choices of economic, social and technological development; however, at the same time, it is bound to be restricted by natural environmental factors such as terrain, soil, hydrology, climate and microorganisms and their comprehensive influence. In recent years, all crops have been affected by climate change and fertilizers (increased use and an increasing trend). Bungau et al. [22] showed that the increasing trend of using fertilizing substances is obvious. Long-term productivity and soil protection are critical to maintaining agricultural ecosystems [23].

There are many studies on drought change in different regions of Xinjiang using different drought indexes; however, there are few studies on dry and wet change in the whole of Xinjiang [22–24]. Xinjiang is not only the main producing area of high-quality cotton, but is also an important production area of wheat and corn. Drought is the main natural disaster in Xinjiang and its occurrence seriously affects agricultural production. Studies on the effects of drought on crop yield in Xinjiang are insufficient. Therefore, this paper analyzes the impact of drought on crops based on the data of 33 meteorological stations in Xinjiang from 1961 to 2020. Here, we assumed that drought will cause the yield of three kinds of crops to decline, and the dry–wet conditions in spring and summer have a greater impact on crop yields. The overall objectives of this study are to: (1) depict the temporal and spatial variation characteristics of the standardized precipitation evapotranspiration index (SPEI) in Xinjiang; (2) analyze the temporal characteristics of the yield of three grain crops; (3) reveal the impact of drought on crop yields. This research can provide scientific support for the early warning of drought and the development of agriculture and animal husbandry in Xinjiang.

2. Data and Methods
2.1. Study Area
Xinjiang lies between 73°40′–96°18′ E and 34°25′–48°10′ N (Figure 1). With a total area of 1.66 million square kilometers, it has the largest land area among all the provincial administrative regions in China. Mountains and basins are alternately distributed, and basins are surrounded by high mountains, forming the geomorphic feature of “three mountains sandwiched with two basins”. Xinjiang is located in the interior of the mainland and is far away from the sea. Coupled with the blocking effect of the surrounding mountains, water vapor from the ocean is not easy to reach, therefore its climate shows obvious continental characteristics. Xinjiang is short of water resources, and the average annual precipitation is only about 150 mm, making drought the most prominent natural disaster.
2.2. Data Source

The meteorological data (monthly mean temperature and precipitation) used in this paper were derived from the Chinese surface meteorological data set (http://data.cma.cn/) (accessed on 27 April 2021) from 1961 to 2020. The meteorological stations with more missing data were excluded, and, finally, 33 meteorological stations were selected. RClimDex was used to strictly check and control the data of the selected stations, including the elimination of outliers and error values, time consistency test, whether the daily minimum temperature was larger than the maximum temperature, extreme value test, etc. In order to ensure the integrity and consistency of data, the linear interpolation method was used to interpolate a few missing data. The spatial distribution was obtained by superimposing DEM, and the influence of altitude, slope and other non-climatic factors was eliminated [25]. Crop yield data came from the National Bureau of Statistics (http://www.stats.gov.cn/tjsj/) (accessed on 11 May 2021), within a time range of 1961–2020.

2.3. Methods

2.3.1. SPEI Calculation Method

SPEI was proposed by Vicente Serrano et al. [15] based on the SPI index. It takes into account the influence of precipitation and evapotranspiration on drought, and has the characteristics of multi-scale and simple calculation. In this paper, the SPEI values on 3- and 12-month time scales were calculated using the monthly mean temperature and precipitation data in the past 60 years. The calculation process [26] is as follows:

Climatological water balance was calculated by the Thomthwaite method:

\[ D_i = P_i - PET_i \]  \hspace{1cm} (1)

where \( P_i \) is precipitation and \( PET_i \) is potential evaporation;

We established the cumulative sequence of water surplus/deficit at different time scales using the following equation:

\[ D^k_n = \sum_{i=0}^{k-1} (P_{n-i} - PET_{n-i}), n \geq k \]  \hspace{1cm} (2)

where \( k \) is the time scale (month) and \( n \) is the number of calculations;
Using the log-Logistic probability density function of three parameters to fit the data sequence established, we obtain:

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

(3)

where \(\alpha\) is the scale parameter, \(\beta\) is the shape parameter and \(\gamma\) is the origin parameter, which can be obtained by the L-moment parameter estimation method. Thus, the cumulative probability for a given time scale can be calculated as follows:

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

(4)

The sequence was transformed into a standard normal distribution to obtain the corresponding SPEI:

\[
SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3}, \quad W = \sqrt{-2 \ln(p)}
\]  

(5)

when \(p \leq 0.5, p = 1 - F(x)\); when \(p > 0.5, p = 1 - P\) and the symbol of SPEI is reversed. Other constant terms are \(C_0 = 2.515517, C_1 = 0.802853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269\) and \(d_3 = 0.001308\).

The SPEI index has multiple time-scale features, and it also reflects the impact of precipitation and temperature on regional drought. It can accurately monitor drought conditions and can be used for comparative analysis of different time-scales and regional drought characteristics [27]. According to the Meteorological Drought Scale [28] developed by the National Meteorological Administration, the SPEI index is divided into different drought levels (Table 1):

| SPEI Value | Drought Grade       |
|------------|---------------------|
| (-0.5–0.5] | Normal years        |
| (-1.0–-0.5] | Slight drought      |
| (-1.5–-1.0] | Moderate drought    |
| (-2.0–-1.5] | Severe drought      |
| (-∞–-2.0]  | Extreme drought     |

2.3.2. Yield Separation Method

The growth of crops not only depends on the adaptation of crops to the local climate, but also on agricultural planting management and other measures which affect the change in grain yield [29]. It is generally believed that grain output is composed of two parts: trend yield and meteorological yield. Trend yield reflects the cultivation methods that humans pay for crop growth and the changes in yield brought about by the improvement of agricultural machinery technology, under normal circumstances, and it is in a state of continuous increase. Meteorological yield means the change in crop yield caused by climatic factors [30]. In this study, the HP filter method [31], which has been verified by previous studies and is applicable to the long-term series analysis of grain yield per unit area in China, was used to separate the meteorological yield of the main grain crops in Xinjiang. Thus, we can assume that:

\[
Y_i = Y_{mi} + Y_{ii}
\]  

(6)
where \(i\) represents the \(i\) years, \(i = 1, 2, 3...; Y_i\) is the actual yield per unit area in year \(i; Y_{mi}\) is meteorological yield; \(Y_{ti}\) is the trend yield and the HP filtering method is to separate \(Y_{ti}\) from \(Y_i\) and minimize the loss function:

\[
\text{Min} \left\{ \sum_{i=1}^{T} (Y_i - Y_{ti})^2 + \lambda \sum_{i=2}^{T-1} \left[ (Y_{t(i+1)} - Y_{ti}) - (Y_{ti} - Y_{t(i-1)}) \right]^2 \right\}
\]  

(7)

In the formula, \(\lambda\) is the smoothing parameter. For annual data, \(\lambda = 100\) has been set in existing studies.

### 2.3.3. Standard Yield Residual Calculation Method

Based on the HP filtering method to separate meteorological yield, in order to compare the effects of SPEI on different crop yields, the standardized yield residual series of meteorological yield was established [32], and the specific methods are as follows:

\[
Y_{ri} = \frac{(Y_{mi} - \mu)}{\sigma}
\]  

(8)

where \(Y_{ri}\) represents the yield residual in year \(i; Y_{mi}\) is the meteorological yield in year \(i; \mu\) represents the average meteorological yield of corresponding crops in all cities and counties of provinces in year \(i; \sigma\) represents the standard deviation of the corresponding meteorological yield. This method has been applied in relevant studies [33,34], and it has been verified that standardized yield residuals can better compare and analyze yield variability between crops, locations and years with different mean values and standard deviations.

### 2.3.4. Other Methods

In this study, Eviews 9.0 was used to filter the yields of grain crops in Xinjiang according to the linear least squares regression method to test the trend of variables, completed by origin. We used normal distribution for correlation analysis and significance test, accomplished by SPSS. The spatio-temporal distribution of SPEI is completed using the inverse distance weight interpolation method of ArcGIS 10.2 software.

### 3. Results

#### 3.1. Annual Variation Characteristics of SPEI in Xinjiang

#### 3.1.1. Time Variation Characteristics

As Figure 2 illustrated, SPEI-12 in Xinjiang revealed significant fluctuations from 1961 to 2020 but decreased at the overall rate of \(-0.17/10a\), indicating that drought continued in Xinjiang in the past 60 years. 1997 was an obvious turning point, and drought occurred less during 1961–1996. From 1997 to 2020, drought was dominant, and the drought intensity was the highest in 2007, 2008 and 2009, and the drought grade was moderate. On the whole, in the past 60 years, Xinjiang has shown a drought trend, and the change trend of drought has obvious interannual characteristics. It was relatively humid in the mid-1970s, late 1980s and mid-1990s, and basically entered a comprehensive drought state in the 21st century. Yao et al. [35] found that, since the middle and late 1980s, the temperature and precipitation in Xinjiang increased, showing the characteristics of “warming and humidification”. However, after 1997, the change trend, frequency and month of drought increased significantly, resulting in more than 70% of the region becoming dry. The climate in Xinjiang exhibited a strong signal of turning from “warm and humid” to “warm and dry”, that is, “wet–dry transition” occurred. Xinjiang experienced widespread drought disasters in 2006 and 2008. Especially, the severe drought in 2008 ranked the second in meteorological records [36,37]. It can be seen that the views of this paper are consistent with the conclusions of previous studies, which indicates that SPEI-12 can be used as a drought indicator in the Xinjiang region for relevant studies.
3.1.2. Spatial Variation Characteristics of the Trend Coefficient

Figure 3 shows the spatial variation characteristics of the trend coefficient of the SPEI-12 index in Xinjiang from 1961 to 2020. It can be seen that the trend of the SPEI-12 index has the characteristics of a regional decline, and the trend coefficient value is $(-0.50 \sim 0.33)/10a$; 69.7% of stations have a downward trend, while 31.3% show an upward trend, that is, drying is the main trend. The trend coefficient of the SPEI-12 index of different meteorological stations was significantly different, and the decreasing area was mainly located in the southeast of Xinjiang. The increasing trend of SPEI-12 was mainly concentrated in the northwest of Xinjiang. It can be seen that the arid trend of Xinjiang is increasing from northwest to southeast.
3.2. Seasonal Variation Characteristics of SPEI in Xinjiang

3.2.1. Time Variation Characteristics

The SPEI-3 index (Figure 4) in Xinjiang increased at a rate of 0.04/10a in winter, but exhibited a downward trend in spring, summer and autumn, with trend coefficients of −0.16/10a, −0.12/10a and −0.13/10a. The interannual variation in spring, summer and autumn in the SPEI-3 index was similar to that of annual SPEI-12 index, both of which had a turning point in 1997. Before 1997, it was mainly wet, and a dry period was entered in 1997. In spring, SPEI-3 showed a very significant downward trend (p < 0.01), especially exhibiting severe drought in 1997 and moderate drought in 2013. In summer, the SPEI-3 index fluctuated significantly, showing an alternation between dry and wet, but displayed a drought trend overall. 2008 was the most severe year of drought, showing a moderate drought. Autumn also changes from wet to dry, and the drought was mainly mild. In 2006, the drought was the most serious, and manifested as moderate drought. In winter, the variation range in the SPEI-3 index was the smallest, showing the alternation of dry and wet. It was relatively dry before 1990, and gradually became wet after 1990.

Figure 4. Seasonal (a) Spring, (b) Summer, (c) Autumn, (d) Winter variations in SPEI-3 index in Xinjiang from 1961 to 2020.

3.2.2. Spatial Variation Characteristics of the Trend Coefficient

It can be seen from the spatial change in the seasonal trend coefficient (Figure 5) that, in spring, the decreasing trend of the SPEI-3 index accounted for 90.91%, which was mainly located in the central and eastern parts of Xinjiang. The SPEI of 13 stations including Turpan and Qiemo showed an extreme significant decreased trend (p < 0.01), and 6 stations including Kumish and Jinghe exhibited a significant decreased trend (p < 0.05). In summer, the decreased trend of the SPEI-3 index accounted for 81.82%, which was mainly located in the eastern part of Xinjiang. Tieganlike, Qiemo and five other meteorological stations were...
significantly decreased ($p < 0.01$); Tacheng and Aksu were significantly decreased ($p < 0.05$).
In autumn, the SPEI-3 index showed a decreasing trend of 84.85%, mainly located in the south and Middle East of Xinjiang, and significantly decreased in 11 stations such as Qiemo and Tulufan ($p < 0.01$). In winter, the SPEI-3 index mainly showed an upward trend, and only accounted for 33.33% of the decrease, which was mainly located in southwest, central and eastern Xinjiang, and significantly decreased in the Shache and Yutian stations ($p < 0.01$). It can be seen that the spatial difference of the trend coefficient of the SPEI-3 in Xinjiang is significant.

Figure 5. Spatial distribution of seasonal (a) Spring, (b) Summer, (c) Autumn, (d) Winter trend in SPEI-3 in Xinjiang during 1961 to 2020.

3.3. Effects of Drought on Crop Yield in Xinjiang

“People are the foundation of the country, and the valley is the livelihood of the people;” food security is an important basis for national security and food production is the key to food security [38]. The problems caused by extreme climate change, such as the spatial imbalance of food production and the sharp decrease in production, have sounded the alarm for food security [39,40]. Xinjiang was well known for its high-quality cotton in the early stage, and it is also an important production area of wheat and corn. To understand the impact of drought on crop yield is of guiding significance to formulate more scientific and reasonable grain and cotton policies in the region.

3.3.1. Variation Characteristics of Crop Yield per Unit Area and Climate Yield

Figure 6 shows the time change of cotton, wheat and corn yield per unit area and meteorological yield over the years in Xinjiang. It can be seen that the yield per unit area of cotton, wheat and corn increased significantly from 1961 to 2020 at the rate of 35.98 kg·hm$^{-2}$·a$^{-1}$ ($p < 0.01$), 105.57 kg·hm$^{-2}$·a$^{-1}$ ($p < 0.01$) and 157.76 kg·hm$^{-2}$·a$^{-1}$ ($p < 0.01$), respectively. Except for cotton, the meteorological yield of wheat and corn showed a weak increasing trend.
3.3.2. Effects of SPEI on Meteorological Yield of Three Kinds of Crops in Xinjiang

The HP filtering method was used to separate the annual yields of three crops in Xinjiang from 1961 to 2020, and then the correlation analysis between the meteorological yield and SPEI was conducted. The results are shown in Table 2.

Table 2. Correlation between SPEI and climate yield in Xinjiang.

|                | Annual | Spring | Summer | Autumn | Winter |
|----------------|--------|--------|--------|--------|--------|
| Cotton         | −0.22  | −0.174 | −0.13  | −0.104 | −0.227 |
| Wheat          | 0.216  | 0.294 * | 0.476 **| 0.032  | 0.051  |
| Corn           | −0.08  | −0.048 | 0.06   | −0.125 | −0.161 |

Note: * represents 0.05 significance, ** represents 0.01 significance.

It can be seen that the meteorological yield of cotton is negatively correlated with SPEI in each period, indicating that drought has little impact on cotton yield. The meteorological yield of wheat was positively correlated with SPEI in different periods, especially with SPEI-3 in spring and summer, indicating that drought was not conducive to wheat yield, especially in spring and summer. The meteorological yield of corn was positively correlated with SPEI-3 in summer, but negatively correlated with SPEI in other periods.

3.3.3. Response of Standard Climate Yield Residual to SPEI-3 in Different Seasons

The standardized residual calculation of meteorological yield of three grain crops in Xinjiang during 1961–2020 was carried out, and regression analysis was carried out between the obtained values and SPEI index in different seasons. Among them, Yr > 0 was set as high yield, Yr < 0 was low yield, Yr = 0 was equal to the annual average and SPEI < 0 was drought or inclined to drought. SPEI > 0 means wet or tending to be wet [41].

The sowing date of cotton in Xinjiang is generally from mid-April to early May. There are regional differences in the picking time. In southern Xinjiang, it is generally in mid-to-late August, and, in northern Xinjiang, it is generally in early October. The growth period...
is about 200 days. As shown in Figure 7, with the increase in SPEI, Yr showed a weak decrease in standard meteorological yield residual. When SPEI < 0 in summer, Yr also increased with the increase in SPEI; however, when SPEI > 0, Yr was basically unchanged and then decreased with the increase in SPEI. In autumn, Yr showed a weak increase with the increase in SPEI. In winter, Yr decreased with the increase in SPEI. The above analysis shows that drought in summer and autumn has the greatest impact on cotton meteorological yield.

Figure 7. Response of cotton standardized meteorological yield residuals to (a) Spring, (b) Summer, (c) Autumn, (d) Winter SPEI-3.

Figure 8 shows the response of the standard meteorological yield residual to SPEI-3. It can be seen that, when SPEI < 0 in spring, with the increase in SPEI, Yr decreased to being basically unchanged; when SPEI > 0, Yr also increased with the increase in SPEI. In summer, with the increase in SPEI, Yr increased to being basically unchanged. In autumn, Yr decreased with the increase in SPEI. When SPEI < 0 in winter, Yr increased slightly with the increase in SPEI; when SPEI > 0, Yr decreased with the increase in SPEI. It can be seen from Table 2 that drought in spring and summer has a great influence on wheat meteorological yield.

The response of standard climate yield residual Yr to SPEI-3 (Figure 9) showed that, when SPEI < 0 in spring, Yr decreased with the increase in SPEI; when SPEI > 0, Yr increased with the increase in SPEI; when SPEI < 0, Yr decreased with the increase in SPEI; when SPEI > 0, Yr increased slightly with the increase in SPEI; with the increase in SPEI in autumn and winter, Yr decreased. It can be seen from Table 2 that drought in spring and summer has a great impact on corn meteorological yield.
Figure 8. Response of wheat standardized meteorological yield residuals to (a) Spring, (b) Summer, (c) Autumn, (d) Winter SPEI-3.

The response of standard climate yield residual $Y_r$ to SPEI-3 (Figure 9) showed that, when SPEI < 0 in spring, $Y_r$ decreased with the increase in SPEI; when SPEI > 0, $Y_r$ increased with the increase in SPEI; when SPEI < 0, $Y_r$ decreased with the increase in SPEI; when SPEI > 0, $Y_r$ increased slightly with the increase in SPEI; with the increase in SPEI in autumn and winter, $Y_r$ decreased. It can be seen from Table 2 that drought in spring and summer has a great impact on corn meteorological yield.

Figure 9. Response of corn standardized meteorological yield residuals to (a) Spring, (b) Summer, (c) Autumn, (d) Winter SPEI-3.

4. Discussion

Based on SPEI, the temporal and spatial variation characteristics of drought in Xinjiang during 1961–2020 were analyzed, and the effects of drought on meteorological yield of grain crops in different seasons in Xinjiang were further analyzed by means of yield separation method and standardized meteorological residual series. The results showed that the SPEI in Xinjiang showed a decreasing trend, that is, a drying trend. The drought occurred less before 1997 and Xinjiang entered a full drought period in 1997. The drought-changing trend was mainly distributed in the southeast of Xinjiang. This is consistent with the results of previous studies. For example, Yao et al. [35] found that, after 1997, the change trend,
frequency and month of drought in Xinjiang increased significantly, and the climate in Xinjiang experienced a “wet–dry transition”. Zhao et al. [42] found that the humidification centers in Xinjiang are mainly located in the western part of Southern Xinjiang, The Yili Valley and the Zhongtian Mountains; however, the eastern Tian Shan Mountains have a drying trend. Due to different drought indexes and different study time spans, the spatial distribution pattern of drought is slightly different; however, the overall trend is roughly the same.

There are regional differences in the impact of climate change on grain crop yield [29]. In this paper, the yield per unit area of three crops in Xinjiang in the past 60 years showed an increasing trend. After the yield separation of the yield per unit area, it was found that, among the three crops, only the meteorological yield of cotton showed an increasing trend, while the meteorological yield of wheat and corn showed a slight downward trend, indicating that climate change was more favorable to the growth of cotton. Gitea et al. [43] found that improving field management and expanding production crop varieties resistant to diseases and insect pests can obtain superior yields. Li et al. [44] found that, in areas that are sensitive to precipitation, heavy rainfall has a greater impact on the increase in wheat yield; in areas that are sensitive to temperature, the increase in extreme high temperature weather has a greater impact on the decrease in wheat production, while the decrease in extreme low temperature weather has a greater impact on the increase in wheat yield. Lunduka et al. [45] found that drought seriously affected corn yield. It can be seen that drought will reduce the yield of wheat and corn. This is consistent with the results of this study.

This paper only studied the effects of SPEI in different seasons on the meteorological yield of different crops in Xinjiang. It can provide scientific support for the early warning of drought in Xinjiang and the development of agriculture and animal husbandry; however, there are still many shortcomings. In fact, the factors of change in food production are extremely complex. In addition to meteorological disasters, they are also affected by deep-seated factors such as planting technology, modern irrigation methods and the integrated management of diseases, pests and weeds. Future research needs to comprehensively consider other meteorological factors (temperature, wind speed, sunshine duration, etc.), underlying surface factors (topography, soil type, hydrological characteristics, etc.) and other factors (pests and diseases, field management, irrigation, etc.), as well as to undertake more in-depth and detailed research to provide the possibility for accurate monitoring and even prediction of agricultural drought.

5. Conclusions

(1) In the past 60 years, the SPEI-12 in Xinjiang has displayed a downward trend, that is, the trend of aridification has strengthened; droughts mainly occurred in the southeast of Xinjiang. (2) In terms of seasonal change, except for winter, the SPEI-3 showed an increasing trend; however, in spring, summer and autumn, the SPEI-3 showed a decreasing trend; in terms of spatial change, the SPEI-3 index mainly increased in winter, and the SPEI-3 index decreased only by 33.33%. In spring, the SPEI-3 index decreased mainly in central and eastern Xinjiang; in summer, the SPEI-3 index decreased by 81.82%; the SPEI-3 index decreased by 84.85% in autumn, and the SPEI-3 index decreased only by 33.33% in winter, mainly in the southwest and east-central of Xinjiang. It can be seen that the SPEI-3 has significant seasonal changes and spatial differences in Xinjiang. (3) In the past 60 years, the yields of cotton, wheat and corn have all increased significantly. Drought is the main cause of reduced wheat and corn production. (4) Drought in spring and autumn had the greatest impact on cotton meteorological yield, while drought in spring and summer had the greatest impact on wheat and corn meteorological yield.
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