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Temporal Dynamics of Standardized Precipitation Evapotranspiration Index and Its Influence to Summer Maize Yield from Kaifeng Region in He'nan Province

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Abstract

Many quantitative studies get more and more attention on drought occurrence and monitoring trends of drought change using different methods; however few studies involve correlation between drought and crop yield especially drought index. This study analyzed the climate change about annual mean SPEI-3, SPEI-6 and SPEI-12, of Kaifeng region in the period of 1961-2013. The SPEI-3 and SPEI-6 seasonal short timescales showed a decreasing tendency, especially rapidly a decline since 2004, and high-frequency alternate dry/wet periods occurred during 1961-2013. However, the annual timescale SPEI-12 showed almost no evidently rise/decline tendency but severity events of dry/wet episode aggravated in terms of duration and magnitude and remarkable low-frequency change. Correlation analysis results between maize yield from Kaifeng region and multi-month scale annual SPEI showed a high negative significant correlation with −0.689 ($\rho < 0.001$) in SPEI-3 and only a negative significant correlation (−0.663, $\rho < 0.001$) in June SPEI-3. Further analysis between maize yield and temperature, precipitation and light during June-September found that precipitation in June and August was the main limiting factor to maize yield and their correlation values were well below the correlation of SPEI-3 of June. Finally, the reconstruction equation found that there was a better change consistency between the maize yield reconstruction and actual production but more error in extremely high and low annual yield. This study provides a reliable analysis of climate change to corn yield and basic data support for services of grain production and food security in the future.

Keywords

SPEI, Dry/Wet Periods, Maize Yield, Correlation Analysis, Kaifeng Region

1. Introduction

With the increasingly apparent global warming, the occurrence of natural disasters such as typhoon, storm, and drought increases considerably. It was noted in 5th IPCC reports that the global surface temperature increased by 0.84˚C during the past century and that climatic warming and drying will enhance the frequency and intensity of extremely meteorological disasters, thus exerting extremely widespread effects on agricultural ecosystems [1]. Drought, one of the most complex natural hazards, affects agriculture and industry, water resources and ecosystems, and society development. The severe drought results in famine, epidemics, land degradation, severe economic losses, even the dynasties change. Previous studies discover drought exerts relatively widespread effects on causing huge economic loss, reduction in food yield, starvation and land degradation [2]-[7]. The research results from Ferrero *et al.* [2] identified that water stress and water management systems were the key causes of the yield gap. In recent years, some quantitative studies get more and more attention on drought occurrence and monitoring trends of drought change [8] [9] using different methods. The SPEI (Standardized Precipitation Evapotranspiration Index) was proposed and became the most useful tool for monitoring the effects of drought occurrence processes [10] [11]. Most studies have been conducted using SPEI to analyze and monitor drought characteristics, variability and trend in China [12] [13] [14] [15] [16]; however a few studies involve the correlation between SPEI and crop yield [17] [18] [19].

As a country in the monsoon region of East Asia, China is climatically vulnerable to frequent meteorological disasters because of its geographical conditions and complex climatic changes [20]. Kaifeng city located on the lower reaches' alluvial plain of the Yellow River, a middle-latitude zone in China and an area of transition between the subtropical zone and the warm temperate zone; drought is one of the most frequent natural disasters such as 1942 extreme drought [21]. However, few studies in the region have analyzed the complexity of drought characteristics using SPEI index and its influence to grain yield.

In this study, we aim to understand the characteristics of drought and wet changes using SPEI index and further probe into correlation between SPEI index and summer maize yield. Thus, the study could provide necessary support for policies concerning drought prevention and alleviation and grain production in the future.

2. Material and Methods

2.1. Study Area

The Kaifeng city is a famous historic and cultural city, it situated in the lower reaches alluvial plain of the Yellow River and a transition area between the subtropical zone and the warm temperate zone of the middle-latitude zone in the eastern China. Located between 113˚52'15"E-115˚15'42"E, 34˚11'45"N-35˚01'20"N, they belong to the central and eastern He'nan Province, including 5 districts and

4 counties, the total area is 6266 km^2. Kaifeng region is a warm-temperate continental monsoonal climate, with cold and dry winter, drought and windy spring, high temperature and rainy summer, fresh autumn and clear four seasons. Average annual temperature ranges from 13˚C to 15˚C, and annual average rainfall of 627.5 mm, more concentrated in the July-August.

2.2. Data Collection

This study used 3-month and 6-month and 12-month SPEI data (1961-2013) from average of ranging between 114˚E-115˚E and 34˚N-35˚N grids and represent for season, half-year and annual scale, respectively. These data are from the European Climate Assessment & Dataset (http://climexp.knmi.nl). SPEI employs the dry and wet gradations as used by SPI in **Table 1** [22].

The meteorological data including temperature and precipitation were obtained from Kaifeng meteorological station (1959-2010) in the China Meteorological Data Sharing Service System and this study select June-September temperature and precipitation during 1991-2010. The summer maize yield data was selected from Kaifeng Statistical Yearbooks [23] during 1991-2011.

2.3. Methods

Trend analysis was used for 3, 6, 12-scale SPEI to understand dry/wet climate change in the study region. Correlation function analyses were performed to investigate maize yield responses to SPEI temporal variation. At last using regression analysis developed a linear regression equation between maize yield and high-correlation SPEI series and do contrast analysis between the actual production of maize and the reconstruction yield.

3. Results and Discussions

3.1. Temporal Dynamics Characteristics Based on Multi-Scale SPEI

The SPEI (Standardized Precipitation Evapotranspiration Index) is a new drought index and accounts for the combined effects of precipitation and potential evaporation (PET) [24] and can represent drought intensity. Its detailed calculation was described by Vicente-Serrano *et al.* [10] and developed a global 0.5˚ gridded SPEI dataset using the CRU dataset [11], which has been used successfully in the European Climate Assessment & Dataset.

Figure 1 shows an evolution of annual mean SPEI over three, six, and twelve months intervals (SPEI-3, SPEI-6 and SPEI-12, respectively) of Kaifeng region in the period of 1961-2013. The two short timescales (three-month and six-month)

Table 1. SPEI drought index gradations.

Mositure Grade	Extremely wet (EW)	Severely wet (SW)	Moderately wet (MW)	Near normal (NN)	Moderately dry (MD)	Severely dry (SD)	Extremely dry (ED)
SPEI	≥2.00	1.50 - 1.99	1.00 - 1.49	−0.99 - 0.99	−1.00 - −1.49	−1.50 - −1.99	≤−2.00

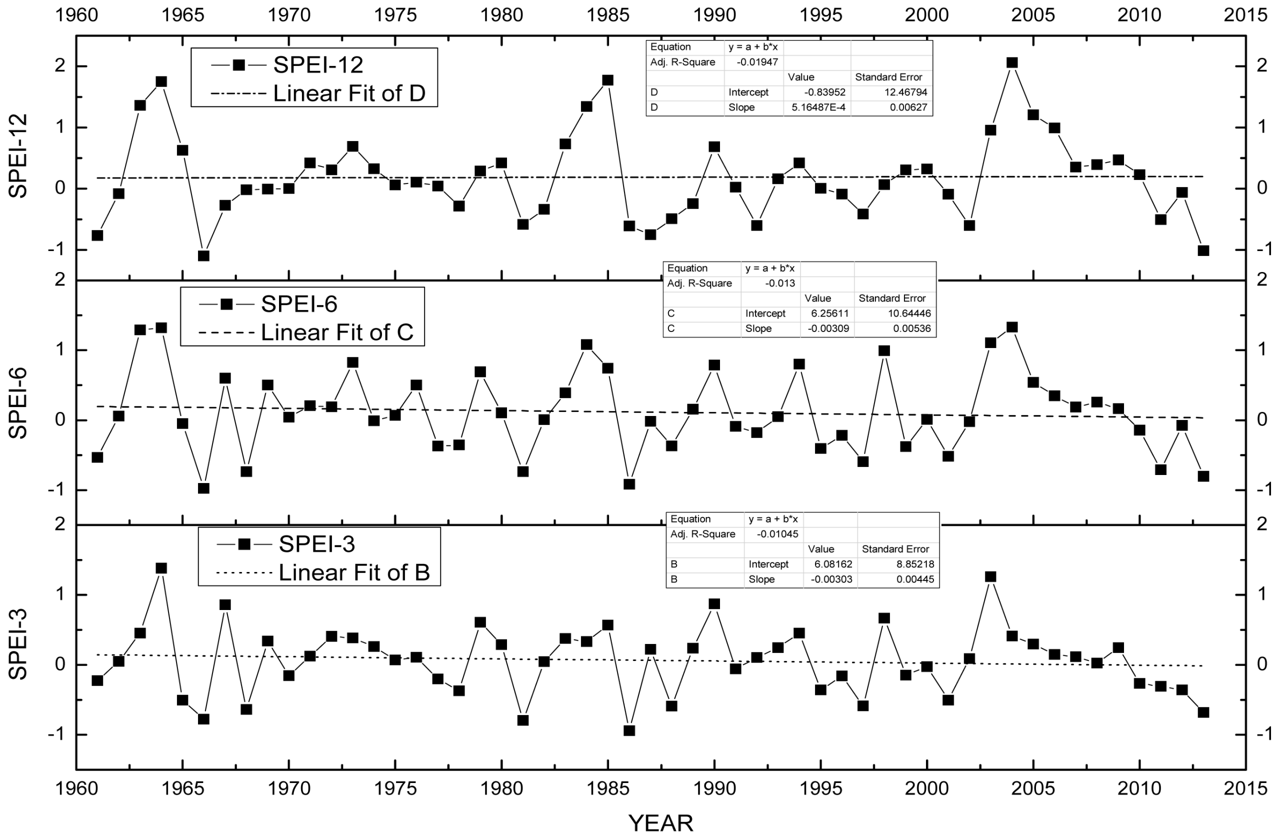

Figure 1. Temporal dynamics characteristics of the 3, 6, 12-month SPEI trend analysis.

showed decreasing tendency (especially the decline has been more rapid since 2004) and high-frequency alternate dry and wet periods occurred during the study period, whereas almost no drought and only two moderately wet year (1 ≤ SPEI < 1.49) in 1964 and 2003 for the three-month series and two moderately wet episodes (1 ≤ SPEI < 1.49) in 1963-1964 and 2003-2004 for the six-month series. There are moderately drought (1 ≤ SPEI < 1.49) in 1966 and 2013 and severely wet (1.5 ≤ SPEI < 1.99) in 1964, 1985 and extremely wet (SPEI ≥ 2.0) in 2004 for twelve-month scale series, as a whole it went in a stabilization trend.

Kaifeng located in the warm-temperate monsoon region of East Asia and precipitation distribution is very uneven. SPEI-3 is more sensitive to short-time precipitation and temperatures and SPEI-6 was affected by pluvial period and dry period over the course of a year, so they showed greater high-frequency variation and downward trend. SPEI-12 maybe influenced by underground water and runoff and no evident rise/decline trend, but severity events of dry/wet episode aggravated in terms of duration and magnitude such as extremely wet (SPEI ≥ 2.0) period was found during 2004, and low-frequency change.

3.2. Correlation Analysis between Maize Yield and SPEI

3.2.1. Correlation Analysis between Maize Yield and Multi-Month Scale Annual SPEI

Correlation analysis between maize yield during 1991-2010 from Kaifeng region and multi-month scale annual SPEI showed high negative significant correlation with −0.689 ($\rho < 0.001$), −0.550 ($\rho < 0.05$) and −0.310 (no significant), respectively. Therefore, the results show that SPEI-3 is an important affecting factor to the yield of maize.

3.2.2. Correlation Analysis between Maize Yield and SPEI-3

Correlation analysis result between maize yield and SPEI-3 (Figure 2) shows there is only negative significant correlation (−0.663) in June with over 99% significance confidence level and negative significant correlation with 95% significance confidence level occur in Summer and growth season of May-September. Maize belongs to Summer growing with June-September and short growth-season crop, so dry/wet in May mainly affected seed germination and early maize growth. Thus, the above results can be seen that the key period of maize growth was June, so the evapotranspiration of water in June is an important affecting factor to the maize yield.

3.2.3. Correlation Analysis between Maize Yield and Climate Factor in Growing Season

In order to better understand relationships between maize yield and June and Summer in SPEI-3, we conduct a relational research between maize yield and temperature, precipitation and light during June-September (Figure 3). The results found that precipitation in June and August are negative significant correlation (−0.468 and −0.546) to maize yield and their correlation values were well below the correlation (0.663) of SPEI-3 in June. June is the embryonic period of maize and August is the filling stage of maize, abundant rainfall in the June and August will reduce the light intensity and result in less photosynthesis and restrict the growth of maize, and precipitation of the two month will result in maize production decreased.

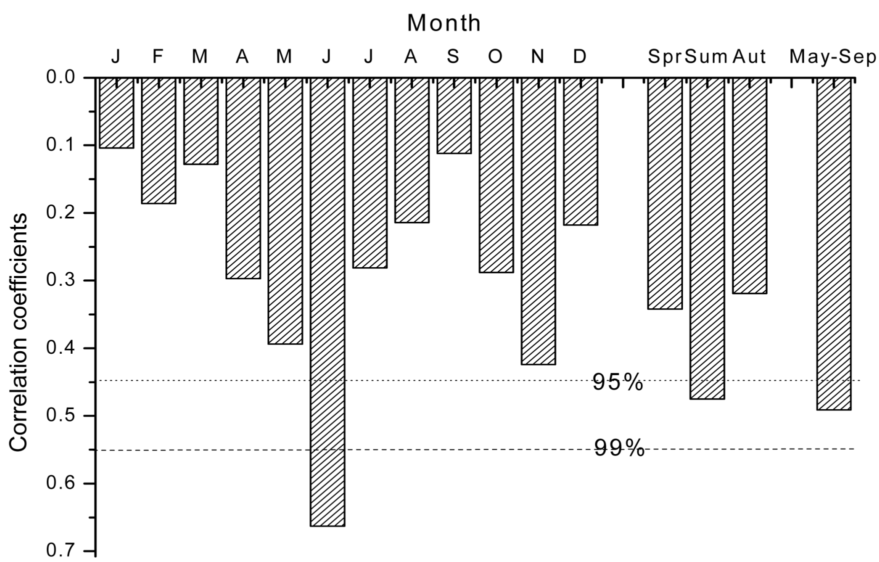

Figure 2. Correlation result between SPEI-3 and maize yield (95% and 99% stand for different significance confidence level).

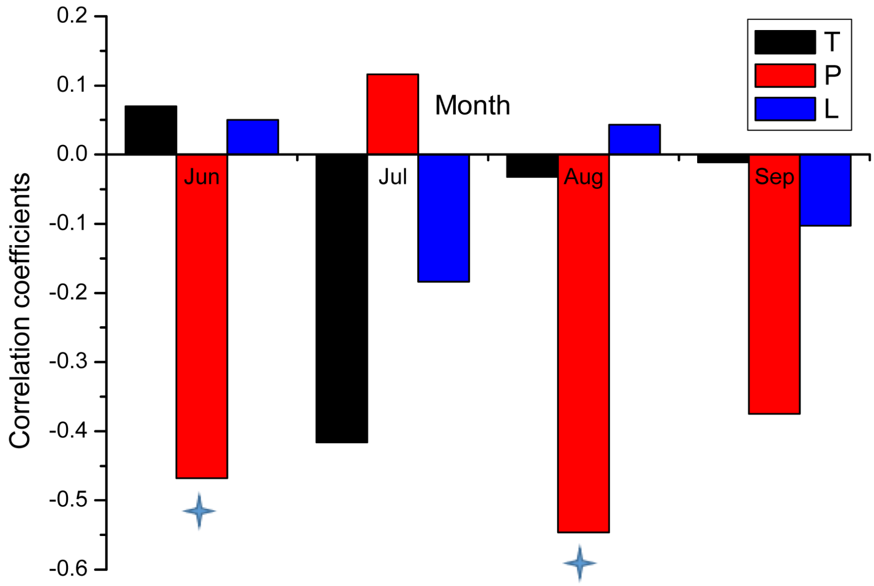

Figure 3. Correlation between maize yield and temperature, precipitation and light during June-September (star stands for 95% significance confidence level).

The above results indicate that summer maize yield is a comprehensive effect of climate factors (temperature, precipitation and light) and soil water rather than a single climate factor, therefore SPEI-3 in June is an important limiting factor for maize yield.

3.3. Reconstruction of Maize Yield and Analysis

From above study results, we developed a linear regression equation about maize yield and June in SPEI-3 (**Figure 4**).

$$Y = -673.6X + 5466$$

There into, Y stand for maize yield and X for June in SPEI-3, R^2 = 0.4398, R^2_{just} = 0.409, F = 14.13, p = 0.001. Higher F and significant verified that the reconstruction equation is reliable.

The study found that there is better change consistency between the maize yield reconstruction and actual production (**Figure 5**), but there lies more error in extreme high and low annual yield. This implied that maize yield was influenced by multi-factors in maize growing period and single factor could not completely interpretation.

This study does not solve the error problem of extreme value. We will research the relationship between the factors of extreme climatic record and maize yield and expect to solve this problem. In the future, we can also use other approaches and records to extend or reconstruct the long scale change sequence of grain production, and predict the possible future food shortage period for social services.

4. Conclusions

This study analyzed the climate change about annual mean SPEI over three, six,

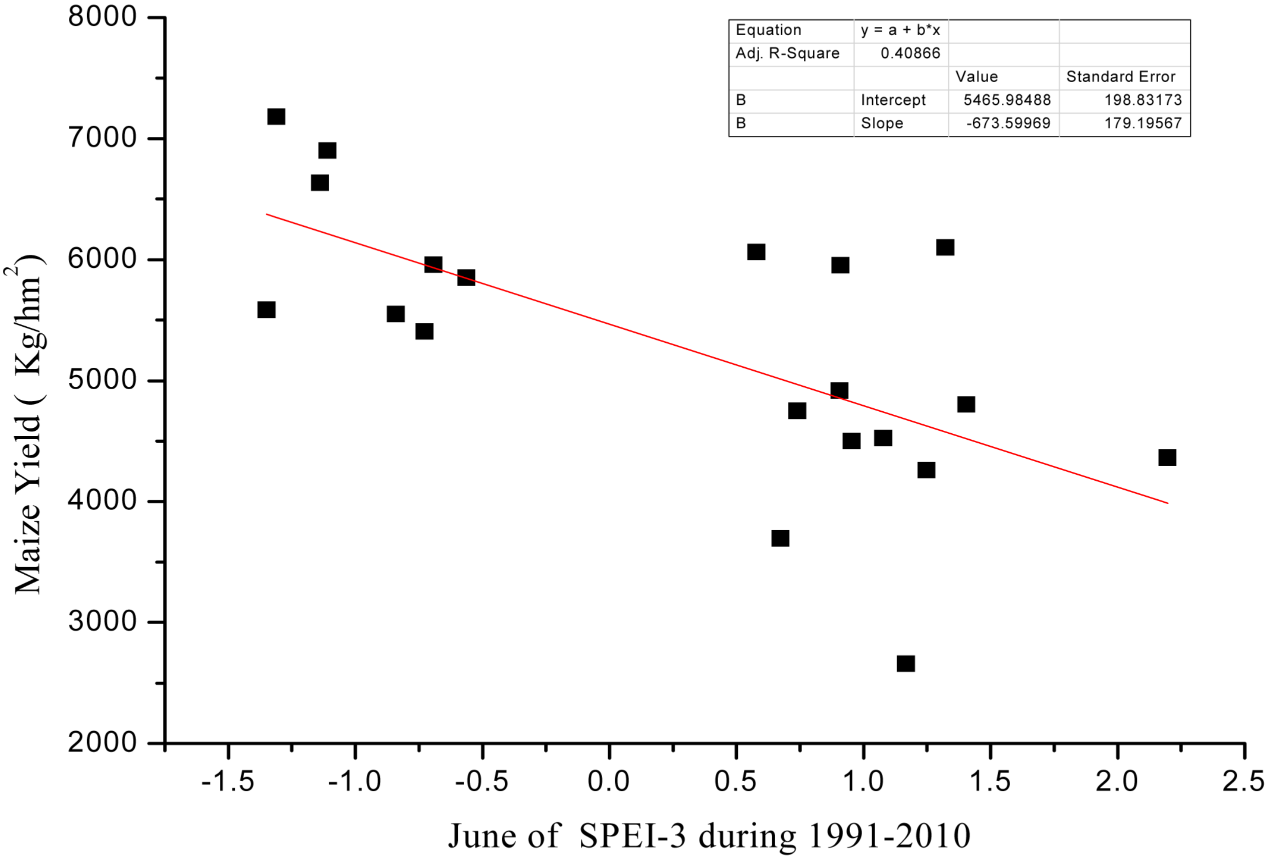

Figure 4. Scatter diagram of regression analysis between maize yield and June of SPEI-3 during 1991-2010.

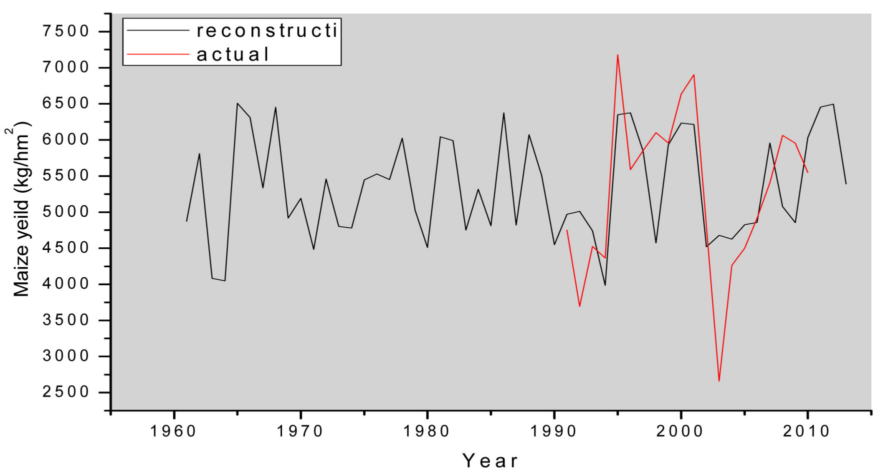

Figure 5. Contrast between the actual production and the reconstruction yield of maize.

and twelve months intervals (SPEI-3, SPEI-6 and SPEI-12, respectively) of Kaifeng region in the period of 1961-2013. The two seasonal short timescales (three-month and six-month SPEI) showed a decreasing tendency (especially the decline has been more rapid since 2004) and high-frequency alternate dry and wet periods occurred during 1961-2013. However, the annual timescale SPEI-12 showed almost no evident rise/decline trend but severity events of dry/wet episode aggravated in terms of duration and magnitude and remarkable low-frequency change.

Correlation analysis results between maize yield from Kaifeng region and multi-month scale annual SPEI showed a high negative significant correlation with −0.689 ($\rho < 0.001$) in SPEI-3 and found only a negative significant correlation (−0.663, $\rho < 0.001$) in June SPEI-3. Further analysis between maize yield and temperature, precipitation and light during June-September found that precipitations in June and August were main limiting factors (correlation −0.468 and −0.546) to maize yield and it is well below the correlation (0.663) of SPEI-3 of June. Finally, the reconstruction equation found that there was a better change consistency between the maize yield reconstruction and actual production but more error in extremely high and low annual yield.

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