Research on the Temporal and Spatial Changes Characteristics of the Drought of Natural Vegetation in the Yangtze River Source Area Based on CWSI

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Abstract: Under the combined effect of global climate change and local regional environmental change, drought has developed into a natural disaster with high incidence on the earth. As the Yangtze River is the mother river of Chinese civilization, the drought phenomenon in the source area in recent decades has seriously affected and restricted the development of local agriculture and economic society. With the long-term practice of remote sensing technology, researchers have improved drought monitoring methods, including crop water stress index. Crop water stress index (CWSI) is widely used in agricultural drought research based on the principle of heat balance. In this paper, the spatial and temporal characteristics of drought in the Yangtze River source area and its influencing factors were analyzed by using crop drought index method. The CWSI value of the source area of the Yangtze River featured a slightly downward trend from 2001 to 2018. With a strong spatial heterogeneity in distribution, it gradually decreases from west to east. The severest drought occurs in summer and autumn, and the regions that are mostly influenced by temperature are mainly in southwest part and the ones mostly influenced by precipitation are mainly in east part. By analyzing the temporal and spatial distribution characteristics of drought and the correlation of meteorological factors, this paper provides an effective basis for drought prevention and control in the Yangtze River source area, and then promotes the accelerated development of agriculture and economic society in the Yangtze River source area of our country.

1. Introduction
The two most important ways to monitor drought is the traditional monitoring method and the remote sensing technology. The traditional method collects and analyzes the observation data of various meteorological stations to draw corresponding conclusions. However, with the limitation of the meteorological station location, it’s not easy to cover the entire study area, so the observed data can’t properly represent the entire area [1].

The emergence and development of remote sensing technology has supplemented the existing monitoring methods. More and more experts and scholars choose to monitor and control the drought conditions on the earth surface through satellite remote sensing [2]. Therefore, the Crop Water Stress Index (CWSI) is widely used in agricultural drought research [3].

As one of the source areas of the three rivers, the source area of the Yangtze River is home to Chinese civilization and culture, and is called the "Mother River of the Chinese Nation". The source of the Yangtze River includes the south part of Qinghai Province and the Zhimenda Hydrologic Station, which locate in the mountains, in the hinterland of the Qinghai-Tibet Plateau. And the plateau is more sensitive to the climate change. In recent decades, the climate at the source area of the Yangtze River
has been changing abnormally, with frequent droughts and reduced rainfall in the rainy season. This affected the normal development of the pastures such as earing and flowering, and accelerated the degradation of the pasture, which severely inhibited the normal agricultural development in these areas [4]. So the research in this paper will help to promote the restoration and development of local vegetation in the source area of the Yangtze River.

2. Overview of the study area
The area from the Tongchun River in Qinghai Province to the mainstream of the Yangtze River is the source of the Yangtze River. It covers an area of about 138,000 square kilometers and covers most of the central part of the Qinghai-Tibet Plateau. The geographical coordinates are about 32°30’—35°50N, 90°30’—97°10E.

![Fig. 1 Location of the Yangtze River Source Area](image)

3. Data sources and research methods

3.1. Data sources
The evapotranspiration data set (MOD16) refers to the reverse data set of the combination of MODIS data and meteorological data based on Penman-Monteith’s formula [6]. The complete set of data includes surface evapotranspiration (ET) [7], potential evapotranspiration (PET) [8], and latent heat flux (LE) [9] and potential latent heat flux (PLE) [10]. The accuracy and temporal and spatial resolution of this data system are very high, and it’s completely free to use. This paper used the synthetic (MOD16A2) evapotranspiration (ET) and potential evapotranspiration (PET) data in the GeoTiff form in the source area of the Yangtze River from 2001 to 2018. The rainfall and air temperature data were obtained from the service website of the National Earth System Science Data Public Sharing Service (http://www.geodata.cn). They were the annual average rainfall data summary of China’s one-kilometer grid and data summary of annual average temperature data from 2001 to 2018 [11].

3.2. Research methods

3.2.1. The Crop Water Stress Index method
Evapotranspiration is the sum of soil evaporation and vegetation evapotranspiration. The evaporation of water from ground plants and the evaporation of soil water are very important in the water cycle. The content of water in the soil has a significant effect on the evapotranspiration rate. If the soil has
sufficient water supply, the evapotranspiration will be very strong, and vice versa [12]. The evapotranspiration with sufficient water supply under certain weather conditions is defined as potential evapotranspiration (PET) [13], and the water evaporation is defined as actual evapotranspiration (ET) when there is insufficient water supply under actual weather [14]. It’s used as an indicator of crop water shortage. The plant transpiration and soil water evaporation are very important in the process of water cycle and they are called evapotranspiration together. Soil moisture content has an important impact on the evapotranspiration rate and will change the vegetation canopy temperature [15].

If the energy received from the land surface is high and the water supply of the surface soil is sufficient, the evapotranspiration will be strong and the vegetation canopy temperature will also be very low. If the content of soil moisture is insufficient, the effect of evapotranspiration will be relatively weak, and the temperature of the vegetation canopy relatively high. Therefore, the temperature of the canopy can be used to indicate the evapotranspiration rate, and thus realize the indirect monitoring of the soil moisture with vegetation cover. The ratio between actual evapotranspiration and potential evapotranspiration is considered as an indicator of crop water shortage. The crop water stress index method comprehensively considers the coverage of the bottom vegetation and the meteorological factors of the land to determine whether the energy is balanced [16]. Jackson [17-18] et al. uniformly defined the Crop Water Stress Index (CWSI) as follows:

\[
\text{CWSI} = 1 - \frac{\text{ET}}{\text{PET}}
\]

(1)

The value of CWSI is between 0 and 1. The higher the value is, the severer the drought is in this area, and the lower the value is, the higher the humidity is in this area.

This paper uses CWSI as drought monitoring indicator. In order to quantitatively analyze the degree of CWSI drought impact calculated based on MOD16 data, we classified it as shown in Table 1 referring to the drought grading standard of the crop water stress index of our country [19].

| Degree of drought      | CWSI value |
|------------------------|------------|
| Extreme drought        | 0.67~1     |
| Severe drought         | 0.63~0.67  |
| Moderate drought       | 0.59~0.63  |
| Mild drought           | 0.5~0.59   |
| No drought             | 0~0.5      |

3.2.2. Linear trend method
This paper adopts the linear trend method to analyze the variation trend and significance of remote sensing image time series based on the pixel scale. This method is currently one of the main methods for judging the trend of the time series data [20], and the calculation formula is

\[
B_{\text{slope}} = \frac{n \sum_{i=1}^{n} (t_i \times \text{CWSI}_i) - \sum_{i=1}^{n} t_i \sum_{i=1}^{n} \text{CWSI}_i}{n \times \sum_{i=1}^{n} t_i^2 - \left( \sum_{i=1}^{n} t_i \right)^2}
\]

(2)

\[
\text{CWSI}_c = \frac{B_{\text{slope}} \times \text{CWSI}}{\text{CWSI}} \times 100\%
\]

(3)

In the formula: \(B_{\text{slope}}\) is the linear trend value; \(t\) is the year; when \(B_{\text{slope}}>0\), with the increase of time \(t\), CWSI shows an upward trend, on the contrary, CWSI shows a downward trend; \(\text{CWSI}_c\) represents the change rate of CWSI (%).

3.2.3. Correlation coefficient method
This paper conducts further research based on the correlation analysis between drought index and meteorological factors. The calculation formula of linear correlation analysis is

\[
R = \frac{\sum_{i=1}^{n} (\text{CWSI}_i - \text{CWSI}) (C_T - \bar{X})}{\sqrt{\sum_{i=1}^{n} (\text{CWSI}_i - \text{CWSI})^2} \sum_{i=1}^{n} (C_T - \bar{X})^2}
\]

(4)
In the formula: R is the correlation coefficient; when R is larger than 0, it means that the relationship between the two elements is positively correlated, and when R is smaller than 0, the relationship between the two elements is negatively correlated; X represents rainfall, temperature or CWSI value of the i-th year; \( \bar{X} \) indicates its average value.

4. Results and analysis

4.1. Drought monitoring based on the Crop Water Stress Index (CWSI) in the source area of the Yangtze River

4.1.1. CWSI interannual temporal and spatial distribution characteristics

(1) Temporal change characteristics

In order to analyze the variation trend of the drought in the source area of the Yangtze River, this paper extracts the average value of CWSI from 2001 to 2018 using the statistical analysis in ENVI and the results are shown in Figure 2. The figure indicates that the CWSI in the source area of the Yangtze River shows an insignificant downward trend from 2001 to 2018, which means that the drought impact in the source area of the Yangtze River has weakened in the past 18 years, but not obviously. The highest average value of CWSI in 2007 reaches 0.726, and the overall performance is severe drought, while the lowest average value of CWSI in 2018 is 0.543, and it is mild drought.

![Fig. 2 CWSI annual variation in the source area of the Yangtze River (2001-2018)](image)

(2) Spatial change characteristics

From figure 3, we can see that the maximum annual average value of ET in the past 18 years is 430.56 mm from 2001 to 2018 in the source area of the Yangtze River, which is concentrated in the east and northeast of Yushu Tibetan Autonomous Region, while the lowest value is 8.44 mm and is concentrated in the western and western margins of the source area of the Yangtze River. The maximum annual average value of PET is 1095.44 mm and concentrated in the Mongolian and Tibetan Autonomous Regions, and the minimum value is 25.6 mm and distributed in the margin areas from the north to the northeast of the source area of the Yangtze River. The maximum annual average value of CWSI is 0.729, which is concentrated in the southwestern part of the source area of the Yangtze River, and the minimum value is 0.169 and distributed in the northern, northeastern and eastern marginal areas. According to the classification of drought grades in Table 1, the Haixi Prefecture is mainly dominated by extreme drought as a whole, and it also shows a gradual transition to no drought from west to east.
Fig. 3 Annual average ET, PET, CWSI and spatial distribution of drought grade in the source area of Yangtze River from 2001 to 2018

The interannual variation trends of ET, PET, and CWSI in the source area of the Yangtze River from 2001 to 2018 is calculated pixel by pixel using the linear trend method, and the CWSI change rate is divided according to the significance. It is divided into six grades including significantly getting wet (slope $<$ 0, $p$ $<$ -0.05), getting wet (slope $<$ 0, -0.5 $<$ $p$ $<$ -0.05), slightly getting wet (slope=0, -0.05 $<$ $p$ $<$ 0), slightly getting dry (slope=0, 0 $<$ $p$ $<$ 0.05), drying out (slope $>$ 0, 0.05 $<$ $p$ $<$ 0.5) and significantly drying out (slope $>$ 0, $p$ $>$ 0.5). See the results in Figure 4. It shows that the maximum ET variation rate in the past 18 years is 13.84/ mm*a-1, and the areas with rapid changes are mainly located in the central, northern and eastern marginal areas of the source area of the Yangtze River. The maximum PET change rate is 34.68/ mm*a-1, and the areas with drastic changes are concentrated in the southwestern marginal area. The maximum change rate of CWSI is 0.008/ a-1, and the areas with the most violent changes are concentrated in the southern marginal area, and the change becomes gradually stable from south to north. After grading the CWSI, we can see that the drought grade of the source area of the Yangtze River lies from slightly getting dry to significant getting wet gradually from south to north, and there scatters significantly drying out and drying out in the southern margin areas.
Fig. 4 Variation rate of ET, PET, CWSI and frequency of drought occurrence in the source area of the Yangtze River from 2001 to 2018

4.1.2. Temporal and spatial distribution characteristics of CWSI during the year
Figure 5 shows the spatial distribution of monthly average CWSI in the source region of the Yangtze River from 2001 to 2018. It can be seen that drought occurs in the source area of the Yangtze River every month in terms of spatial distribution. Specifically, the impact of drought in the source area of the Yangtze River increases in January and February when the season changes from winter to spring. The impact weakens in March, and area impacted by severe drought will increase from April to June when the season changes from spring to summer, and they are mainly distributed in the southwestern areas. From July to September, the severe drought areas increase in the western and central regions. From October to December, the areas with severe drought lie again in the south and southwest regions.
Fig. 5 Monthly average CWSI spatial distribution in the source areas of the Yangtze River, 2001~2018

The variation trends of monthly average CWSI in the source area of the Yangtze River from 2001 to 2018 is calculated pixel by pixel using the linear trend method, and is divided according to the significance. The result shows in figure 6. As it shows in the figure, the areas where the drought shows an increasing trend from January to February gradually increase from south to north. The drought in the whole region shows a significant weakening trend from March to April and increases significantly again in May. From June to July, the areas where the drought shows a weakening trend gradually increase. The drought in the whole area shows an increasing trend in August and the drought change weakens in September. From October to December, when the season changes from autumn to winter, the areas with severe drought trend gradually increase.
4.2. Correlation analysis between drought changes and meteorological factors

In order to explore the relationship between CWSI variations and meteorological factors, ArcGIS software was used to interpolate the annual meteorological data and get the spatial distribution of the precipitation and average temperature in the source area of the Yangtze River from 2001 to 2018. Then the relevant data was used to analyze and calculate the relationship between CWSI and two different meteorological factors.

Figure 7 shows the correlation between CWSI and the average temperature and precipitation. In terms of spatial distribution, the correlation coefficient of CWSI and precipitation in the source area of the Yangtze River is from -0.74 to 0.38, and the correlation coefficient of CWSI and temperature in the source area of the Yangtze River is from 0.57 to 0.53. The areas with strong correlation between CWSI and average temperature in the source region of the Yangtze River are mainly concentrated in the eastern part of Yushu Tibetan Autonomous Region, while the southern and western parts of Haixi Prefecture show relatively high correlation with precipitation.

5. Conclusion

(1) Since the past 18 years, the drought in the source region of the Yangtze River has shown a weakening trend, and the severe drought areas have been mainly concentrated in Haixi Prefecture; (2) The severe drought in the source region of the Yangtze River mainly occurs from April to October; (3) The drought in the Yushu Tibetan Autonomous Region mainly depends on the local precipitation;
while the drought in the Haixi Prefecture mainly depends on the local temperature changes. The emphasis of the drought prevention and control in summer is in the south part near Tibet while it is in the eastern region in winter.

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