Characteristics of NDVI Temporal and Spatial Variation in the Source Area of the Yangtze River and Its Response to Hydrothermal Conditions

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Abstract: vegetation cover change monitoring is the basis of regional resources and environmental carrying capacity research. Based on the data set MODIS-NDVI 2001~2018, this paper analyzes the spatial and temporal characteristics of annual NDVI in the Yangtze River source area by using maximum synthesis method and various statistical methods. The effects of surface hydrothermal conditions on space and time were discussed. The results show that: 1) the NDVI of the source area of the Yangtze River shows a significant increase trend, and only some areas of Dongyuan NDVI show a downward trend. In spatial distribution, the vegetation coverage in the source area of the Yangtze River is mainly low and medium vegetation coverage, the vegetation coverage increases gradually from northwest to southeast, and the vegetation coverage of Yushu Tibetan Autonomous region is generally higher than that of Hercynian Mongolian Tibetan Autonomous region. At above 4000 m, the vegetation coverage increases more obviously with the increase of altitude. 2) precipitation in the source area of the Yangtze River decreases gradually from southeast to northwest, the low value area is located in the north of the source area of the Yangtze River, and the high value area is located in the eastern part of the Yushu Tibetan Autonomous region. However, the spatial trend of annual mean temperature and precipitation in the source area of the Yangtze River is opposite. The precipitation tendency rate in the source area of the Yangtze River shows obvious spatial difference, the precipitation in the south source generally shows a decreasing trend, and the precipitation in the north source generally shows an increasing trend. The southwest source and east source NDVI of 3) Yangtze River source area are negatively correlated with precipitation, while NDVI and temperature are positively correlated in most areas of the Yangtze River source area, and the effect of temperature on interannual variation is stronger than that of temperature. With the increase of temperature and precipitation, the NDVI also shows an increasing trend in spatial distribution, but precipitation has a stronger effect on the spatial heterogeneity of NDVI. From this we can see that the influence of hydrothermal conditions on the interannual variation of NDVI depends on the temperature, while the effect on spatial distribution mainly depends on the precipitation.

1. Introduction

The normalized difference vegetation index (NDVI) is generally used to describe the growth of vegetation, and can be used to quantitatively measure the growth of vegetation under certain conditions. It is an important indicator to measure the degree of surface vegetation coverage and describe the ecosystem environment, which is of great importance to the research fields of water and soil conservation, regional environmental quality assessment, air pollution, etc[1-3].

At present, the traditional ground observation methods for observing the (NDVI) mainly include three main methods, that is, estimation method, sampling method and instrument method [4], which is
relatively accurate and objective. However, there are also obvious shortcomings of time consuming, high manpower and material resources. Moreover, ground observations can only be applied to micro-scale research, to a certain extent, which is difficult to extend to a macro perspective, especially large-area continuous observation of time and space \[5\]. With the rapid development of remote sensing technology, it has largely made up for the shortcomings of traditional research mechanisms and monitoring methods. More researchers choose to monitor the dynamic changes of the surface through satellite remote sensing \[6-8\]. The advantage of remote sensing technology is that it can obtain information such as the dynamic changes of the surface in a timely and rapid manner, and it can monitor the growth of vegetation in the target area continuously in time and space. It can obtain information more quickly and timely, with wider coverage and stronger dynamic variability \[9\], which can realize synchronous monitoring in a large area. Therefore, remote sensing technology has also been widely used in monitoring the growth of vegetation. Zhao Jie et al. \[10\] analyzed the temporal and spatial changes of vegetation in the upper and middle reaches of the Heihe River basin and its response to water and heat conditions based on the SPOT-NDVI ten-day data and the ten-day data of temperature and precipitation from 1999 to 2010. Luo et al. \[11\] used NDVI as an indicator to analyze the characteristics of the temporal and spatial changes of NDVI during the comprehensive management project from 2000 to 2013, and explored and distinguished the range and extent of the influence of precipitation, temperature and climate factors, as well as human activities on vegetation cover changes. Liu \[12\] and others used MODIS-NDVI data, combined with trend analysis methods and coefficient of variation to analyze the spatiotemporal characteristics and spatial stability of vegetation NDVI on the Yunnan-Guizhou Plateau from 2001 to 2014. In summary, the current research on the characteristics of temporal and spatial variation of NDVI and its influencing factors are mostly focused on analyzing the impact of its interannual changes in precipitation and temperature on NDVI. However, NDVI is also affected by the spatial heterogeneity of climate. This paper takes the source area of the Yangtze River as the research object, and uses the MODIS data to extract the vegetation coverage data of China from 2001 to 2018, and uses trend analysis and correlation coefficients to determine the interannual change trend of NDVI and the effect of interannual climate change on NDVI. The NDVI value corresponding to the pixel value of precipitation and temperature is extracted, and the influence of climate spatial heterogeneity on NDVI is analyzed, aiming to further understand the ecological environment in the source area of the Yangtze River and provide a certain reference for the macro-layout and implementation of relevant ecological construction projects.

2. Overview of the Research Area
The topography of the source area of the Yangtze River is mostly high mountains, with an average elevation of 4000 m or higher \[11\]. The source area of the Yangtze River has a plateau continental climate, and the year is divided into two solar terms: winter and summer, with obvious alternating between dry and wet. The annual average temperature is -5.3°C to 3.3°C, and the annual average precipitation is 284mm–511mm, so the vegetation coverage is low \[11\]. The vegetation types in the source area of the Yangtze River are distributed from southeast to northwest in the order of ecological types, such as alpine meadows, alpine grasslands, and sparse vegetation on alpine stream rock beaches. The soil in the source area of the Yangtze River has a low degree of soil formation and simple structure types. The soil in the source area of the Yangtze River has a low degree of soil formation and simple structure types, with main types of mountain meadow soil of mountain steppe meadow soil, alpine shrub meadow soil, alpine cold desert soil, alpine steppe soil and alpine desert steppe soil, etc \[12\].
3. Data Sources and Research Methods

3.1. Data source and processing
This article selects the MOD13A3-NDVI remote sensing data set, with the time scale from 2001 to 2018, sourced from the National Aeronautics and Space Administration (NASA) (https://ladsweb.modaps.eosdis.nasa.gov). The time resolution is monthly-scale, and spatial resolution resampling is 3km×3km. With the help of MRT software provided by NASA, the original HDF format is converted to Geo-Tiff format, the SIN projection is converted to WGS-1984/Geographic latitude and longitude coordinate system, with pre-processing of mosaic and cropping performed. Then, the pre-processed NDVI data is synthesized into annual-scale data by the maximum synthesis method \(^{[13]}\) (Maximum Synthesis Method, MVC), which further eliminates the influence of clouds, atmosphere, and sun altitude on the NDVI monitoring value.

The meteorological data used in this paper is the monthly average temperature and monthly precipitation data set provided by China Meteorological Network (http://data.cma.cn/). In order to ensure the continuity and completeness of the data, this paper deletes the stations with missing or abnormal values from 2001 to 2018, selects a total of 11 meteorological stations in or near the study area, calculates the average value of the temperature data for 12 months of each year, and sums the precipitation data \(^{[14-17]}\). Both air temperature and precipitation data use radial basis function interpolation (RBF) for spatial interpolation. The main reason for using this interpolation method is that this method is relatively more robust than inverse distance weight interpolation (IDW). When the sampling point data has great certainty, the error of this method is low. However, IDW is more suitable for mountainous areas rather than grassland areas, which does not match the actual situation of the study area. Therefore, it is much more appropriate to apply RBF to carry out researches in this area \(^{[19-20]}\).

3.2. Research Method

3.2.1. Maximum Synthesis Method
MVC (Maximum Value Synthesis) is an internationally recognized NDVI data synthesis method, which
can eliminate interferences of air pollution, cloud and sun elevation angle and other factors [21].

In this study, we selected the NDVI value of the source region of the Yangtze River from January to December in 2001 to 2018. Through the maximum value synthesis method, the maximum value of each pixel was extracted as the NDVI value of that year. The formula is:

\[ NDVI_y = \text{MAX}(NDVI_i) \quad i = 1, 2, \ldots 12 \]  

(1)

Where, \( NDVI_y \) represents the annual scale value of NDVI, and the value of \( i \) is 1-12, representing the NDVI value from January to December, respectively.

### 3.2.2. Linear Regression Slope Method

In order to study the change trend of vegetation coverage in the source area of the Yangtze River from 2001 to 2018, the linear regression slope method is used in this paper [22].

The inter-annual variation trend of NDVI is inverted on a pixel-by-pixel scale, and the spatial variation of the vegetation change rate is also analyzed during the study period. When the change rate is greater than 0, it means that the vegetation coverage increases over time, with a trend of improvement of the vegetation growth. On the contrary, when the change rate is less than 0, it means that the vegetation coverage decreases over time, with a deteriorating trend of vegetation growth.

The calculation formula is:

\[ \text{slop} = \frac{n \sum_{i=0}^{n}(t_i \times NDVI_i) - \sum_{i=0}^{n} t_i \sum_{i=0}^{n} NDVI_i}{n \sum_{i=0}^{n} t_i^2 - (\sum_{i=0}^{n} t_i)^2} \]  

(2)

Where, \( \text{slop} \) is the linear tendency rate, \( t_i = 2001, 2002, ..., 2018 \), \( n \) is the total length of the annual sequence (\( n = 18 \)) and \( NDVI_i \) represents the NDVI value of the \( i \)th year. When \( \text{slop} > 0 \), \( NDVI \) shows an upward trend with the increase of \( t \), otherwise, it shows a downward trend.

### 3.2.3. Correlation Analysis

The correlation between the NDVI value of each pixel in the source area of the Yangtze River and precipitation and temperature can be calculated by using a simple correlation coefficient to express. The calculation formula is shown below.

\[ r = \frac{\sum_{i=0}^{n}[NDVI_i \times \overline{NDVI} \times (X_i - \overline{X})]}{\sqrt{(NDVI_i - \overline{NDVI})^2 \sum_{i=0}^{n}(X_i - \overline{X})^2}} \]  

(3)

Where: \( r \) is the simple correlation coefficient between two variables. \( \overline{NDVI} \) is the average value of NDVI from 2001 to 2018. \( X_i \) represents the value of precipitation or temperature in the \( i \)th year; \( \overline{X} \) represents the average value of precipitation or temperature from 2001 to 2018. Other physical meanings are the same as before.

### 4. Results and Analysis

#### 4.1. Temporal and Spatial Distribution Characteristics of NDVI in the Source Region of the Yangtze River

The NDVI data of the source area of the Yangtze River from 2001 to 2018 obtained by the maximum synthesis method. The average value of the NDVI of the source area of the Yangtze River from 2001 to 2018 can be obtained using the statistical tools in ENVI, as shown in Figure 2. It can be seen from Figure 2 that the NDVI value of the source area of the Yangtze River is between 0 and 0.44. The vegetation coverage is dominated by low and medium vegetation coverage [23], with higher vegetation coverage amid dense-river areas. In terms of spatial distribution, the vegetation coverage gradually increases from northwest to southeast. The vegetation coverage in Yushu Tibetan Autonomous Region is generally higher than that in Haixi Mongolian and Tibetan Autonomous Prefecture.

On this basis, in order to learn about the influence of topographic factors on the NDVI of the source area of the Yangtze River, this paper extracts the average value of NDVI at different elevations, as shown in Figure 3. It can be seen from Figure 3 that the vegetation coverage in the source area of the Yangtze River shows a decreasing trend as the altitude increases. Specifically, the change of NDVI with altitude
can be divided into two stages. When the altitude is below 4000 m, with the increase in altitude, the change of vegetation coverage is relatively stable, and there is basically no change. For every 100 m increase in altitude, its NDVI decreases by 0.0002. When the altitude is above 4,000 m, NDVI presents a rapid downward trend with the increase in altitude, and the NDVI decreases by 0.009 for every 100 m increase in altitude. This is mainly because low-altitude areas in the source area of the Yangtze River have relatively better water and heat conditions and are more suitable for vegetation growth, while high-altitude areas have a harsher ecological environment, especially low temperatures, which are not suitable for vegetation growth. Therefore, as the altitude increases, the vegetation coverage shows a decreasing trend.

![Fig. 2 Annual average of NDVI in source areas of the Yangtze River](image1)

In order to further analyze the spatial change trend of NDVI in the source area of the Yangtze River, this paper calculates the rate of change of NDVI on a pixel-by-pixel scale, and conducts a significant test of the correlation coefficient, as shown in Figure 4. It can be seen from Figure 4 that from 2001 to 2018, the NDVI in the source area of the Yangtze River showed an upward trend as a whole, with an average increase of 0.007/10a. The vegetation coverage in the eastern part of the source area of the Yangtze River has decreased significantly, while that in the northwest has increased significantly, due
to the implementation of a series of ecological environmental protection projects in the northwest in recent years. Under the intervention of human activities, the vegetation coverage has shown an obvious increasing trend.

4.2. Temporal and Spatial Variation Characteristics of Hydrothermal Conditions in the Source Region of the Yangtze River

Figure 5 shows that the annual average precipitation in the source area of the Yangtze River from 2001 to 2018 ranged from 269.36 mm to 539.15 mm, with an average of 404.3 mm. The precipitation gradually decreased from the southeast to the northwest. The low value area was located in the north source and real source of the source area of the Yangtze River, Hezhengyuan, while the high-value area is located at the southern source and downstream of the source area of the Yangtze River. The multi-year average temperature in the source area of the Yangtze River is between -4.27°C and 4.15°C, with a multi-year average value at -0.06°C. The temperature in the source area of the Yangtze River has a large spatial difference, with as high as 8°C, which is the same as the spatial change trend of precipitation, indicating that precipitation and temperature have the same changing trend, that is, areas with low temperature have relatively low precipitation.

On this basis, the change trends of annual precipitation and annual average temperature are calculated, with the results shown in Figure 6 and Figure 7. It can be seen from Figure 6 that the precipitation tendency rate of the source area of the Yangtze River shows a relatively obvious spatial difference. The
precipitation of the south source generally shows a decreasing trend, while the precipitation of the north source generally shows an increasing trend (Figure 6(a)). However, from the point of view of the significance of the change trend, the area with significant changes in precipitation in the source area of the Yangtze River only accounts for less than 10% of the basin area. Areas with a significant upward trend are mainly distributed in a small part of the central part of Beiyuan (Figure 6(b)). Overall, the temperature in the source area of the Yangtze River generally shows an increasing trend, especially in the south source and most of the east (Figure 7(a)). The significant test results show that the area with significant temperature changes in the source area of the Yangtze River accounts for more than 98% of the area of the source area of the Yangtze River, with a significant increasing trend in almost all areas, which that is not strong concentrated in the adjacent areas of Sichuan (Figure 7(b)). This also further illustrates that the main reason for the decrease in vegetation coverage in Yushu area may be caused by the decrease in precipitation.

4.3. The response of NDVI in the Source Region of the Yangtze River to Hydrothermal Conditions
In order to explore whether the decrease and increase of precipitation and temperature will cause changes in vegetation coverage, this paper calculated the correlation between NDVI and precipitation and temperature on a pixel-by-pixel scale. The results are shown in Figure 8. It can be seen from Figure 8 that the average correlation coefficients of NDVI, precipitation and temperature in the source area of the Yangtze River are 0.08 and 0.34, respectively, indicating that the inter-annual variation of NDVI in
the source area of the Yangtze River is mainly affected by temperature, while precipitation has little effect on the inter-annual variation of NDVI. Specifically, the NDVI of the south source and lower reaches of the source area of the Yangtze River is negatively correlated with precipitation, indicating that the vegetation coverage shows a downward trend as precipitation increases. This may be mainly because when the amount of precipitation increases, the amount of water used for irrigation decreases, resulting in a drop in vegetation coverage, compared to little amount of precipitation. However, the NDVI and temperature are positively correlated in most areas of the source of the Yangtze River, indicating that as the temperature rises, the vegetation coverage also shows an increasing trend.

Fig. 8 Relationship between mean precipitation, temperature and NDVI over the years

In order to further analyze the influence of the spatial heterogeneity of precipitation and temperature on NDVI, this paper extracts the NDVI values corresponding to different precipitation and temperature and draws them into a scatter diagram as shown in Figure 10. It can be seen from Figure 10 that the influence of precipitation and temperature in the source area of the Yangtze River on the spatial distribution of NDVI is positively correlated, while the influence of precipitation on the spatial distribution of NDVI is stronger than that of temperature. Specifically, for every 100 mm increase in precipitation, NDVI increases by 0.1, while for every 1°C increase in temperature, NDVI increases by 0.02. Therefore, there are obvious differences in the influence of hydrothermal conditions on the temporal and spatial changes of NDVI in the source area of the Yangtze River. The influence of hydrothermal conditions on the interannual variability of NDVI depends on temperature, while the influence on spatial distribution mainly depends on precipitation.

Fig. 9 Spatial distribution of correlation between vegetation NDVI and precipitation

5. Conclusion
This paper uses MODIS-NDVI data, applies methods such as maximum value synthesis, linear tendency
estimation model and correlation coefficients to extract the NDVI in the source area of the Yangtze River from 2001 to 2018. It also analyzes its temporal and spatial characteristics. On this basis, the influence of hydrothermal conditions on the temporal and spatial changes of NDVI is analyzed. The main conclusions are as follows:

Firstly, NDVI showed significant increases as a whole in the source area of the Yangtze River, with a downward trend in only some areas. Ecological protection measures in these areas should be strengthened to prevent further deterioration of vegetation coverage. In terms of spatial distribution, the NDVI value of the source area of the Yangtze River is between 0 and 0.44. The vegetation coverage is dominated by low and medium vegetation coverage, with gradually increases from northwest to southeast. The vegetation coverage in the Yushu Tibetan Autonomous Region is generally higher than that in Haixi Mongolian and Tibetan Autonomous Prefecture. In addition, the vegetation coverage in the source area of the Yangtze River shows a downward trend as a whole, with the increase in altitude. When the altitude is above 4000m, the increase in vegetation coverage is more obvious.

Secondly, the precipitation in the source area of the Yangtze River gradually decreases from the southeast to the northwest, which is the same as the spatial change trend of temperature. In addition, the precipitation trend rate in the source area of the Yangtze River shows obvious spatial differences. The precipitation in the south source generally shows a decreasing trend, while that in the north source generally shows an increasing trend.

Thirdly, the NDVI of the source area of the Yangtze River is positively correlated with temperature in most areas of the source of the Yangtze River. The influence of temperature on the interannual variability of NDVI is stronger than that of temperature, indicating that NDVI is more sensitive to temperature in terms of interannual variability. In terms of spatial distribution, as temperature and precipitation increase, NDVI also shows an increasing trend, but precipitation has a stronger impact on the spatial heterogeneity of NDVI. The influence of hydrothermal conditions on the interannual variability of NDVI depends on temperature, while the influence on spatial distribution mainly depends on precipitation.

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