

Spatial and temporal changes in inter-annual and seasonal NDVI in the Qinling mountains of China

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Abstract. As an important ecological barrier in central China, the Qinling Mountains have received more attention in response to global or regional climate change. Spatial and temporal changes of inter-annual and seasonal NDVI were analysed after extraction of the vegetation growth season, based on MODIS NDVI images and linear trend analysis. The results showed that: (1) the NDVI value and vegetation cover level of the Qinling Mountains were high. The NDVI showed significant annual and seasonal increases, in which the summer value contributed the most to the inter-annual value, followed by spring and autumn. In terms of the change trend, the NDVI showed a linear increase in annual and seasonal data, in which the spring growth rate contributed the most to the inter-annual value, followed by autumn and summer. (2) The spatial distribution of the linear change trend of the NDVI in the inter-annual and seasonal data was mainly increased, but the area of reduction was also large. The area of reduced NDVI was mainly distributed in the middle and western area with middle and high elevations, as well as urban neighbourhoods with intensive human activities, such as the Hanzhong basin, the Ankang basin, and the Shangluo basin. The rate of change in NDVI in human activity areas was higher than in the middle and higher elevation areas. The change may be driven by human activities in the former and by climate change in the latter. Monitoring of the vegetation ecological system in the Qinling Mountains should be strengthened to understand the change process, as well as to provide a scientific basis when making policies for regional ecological environmental protection.

1. Introduction

The global climate change process has a significant impact on terrestrial ecosystems. At the same time, terrestrial ecosystems also feed back to the climate to a certain extent [1-2]. Under the background of environmental change, which is marked by global warming, the changes in terrestrial ecosystems and their impacts have played an important role not only in international political and economic policies, but also in the sustainable development of human society [3-4].

Due to its complex terrain and diverse climate type, the Qinling Mountains have become a popular and sensitive area for studying regional response to global climate change, and it is an important area for climate change research and a good experimental site [5-7]. As a natural "link" to connect the



atmosphere, hydrosphere and lithosphere, vegetation is not only an important organic component of terrestrial ecosystems, but it also serves as an “indicator” in global climate change research [8-9]. The Normalized Difference Vegetation Index (NDVI) is calculated by using the spectral reflection characteristics of vegetation in different bands. NDVI data can reflect the changes of surface vegetation cover, biomass and ecosystem parameters to a certain extent. This is the main use of data sources in the world and is widely used at scales such as the global scale [10-11], the intercontinental scale [12-13], geographical units [14-15], and the administrative division scale [16-17].

Current research on vegetation ecosystems in the Qinling Mountains has been more concerned with spatial and temporal spatial changes in the inter-annual scale, whereas the seasonal variation of vegetation has been of less concern. This paper analyzed the spatial and temporal changes of inter-annual and seasonal NDVI by the extraction of the vegetation growth season, based on MODIS NDVI data of 250 m resolution and 16 d synthesis from 2000 to 2015. This research will provide a scientific basis for the ecological protection of mountain vegetation.

2. Methods

2.1. Study sites

The Qinling Mountains represent an important dividing line between southern and northern China, temperate and subtropical climates, and the Yangtze River and Yellow River watersheds. This paper focuses on the Qinling Mountains in Shaanxi Province, with a geographical range of 105°30'-110°05'E and 32°40'-34°35'N, including a small part of the southern Guanzhong Plain and most parts of Ankang, Hanzhong and Shangluo, with an area of about 7.06×10^4 km². Due to the rich variety of water and temperature conditions and climate types, the Qinling Mountains have a complex and rich mountain ecosystem (Figure 1).

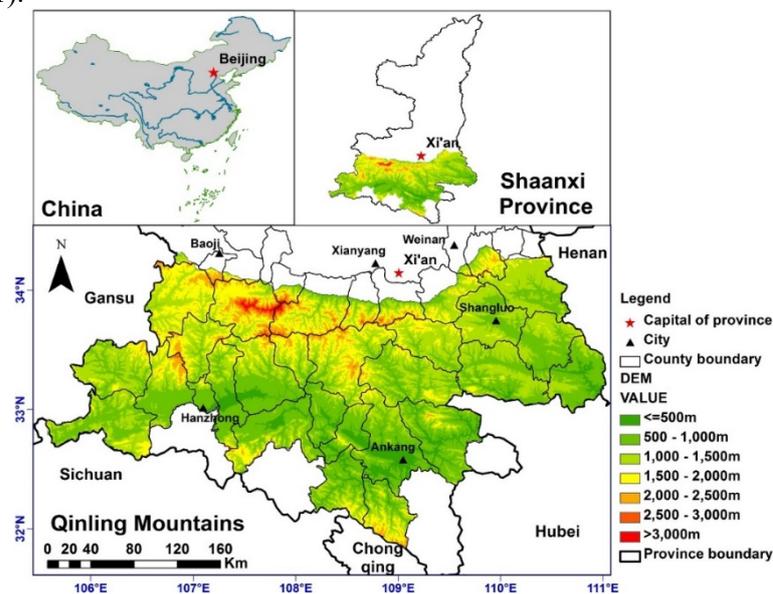


Figure 1. The location of the Qinling Mountains

2.2. Data

The study used MODIS NDVI 13Q1 products (download from <http://ladsweb.nascom.nasa.gov>) with data from 2000 to 2015 at 250 m resolution and 16 d synthesis. MODIS NDVI data in space-time resolution can meet the requirements for reflecting changes in vegetation. The MODIS NDVI time series data were obtained by using Modis Reprojection Tools (MRT) to decode, splice, re-project and format the data.

2.3. Linear trend analysis

Linear trend analysis can be used to analyze the NDVI spatial and temporal change process and the possible future direction of NDVI in the Qinling Mountains. The calculation formula is as follows [18]:

$$Y = aX + b \quad (1)$$

$$a = \frac{\sum_{i=1}^n x_i y_i - n \bar{x} \bar{y}}{\left(\sum_{i=1}^n x_i^2 - n \bar{x}^2 \right)} \quad (2)$$

where $Y(y)$ is the NDVI value or spatial distribution data of the study area from 2000 to 2015; $X(x)$ is the year from 2000 to 2015; a is the coefficient; b is a constant; and \bar{x} and \bar{y} are the average of X and Y , respectively. Positive or negative values of a indicate an increase or decrease in the linear trend.

3. Results

3.1. Vegetation growth season

Based on the MODIS NDVI time series images from 2000 to 2015, the average NDVI in the same period was calculated, and the NDVI average curve and slope curve from 2000 to 2015 was obtained (Figure 2).

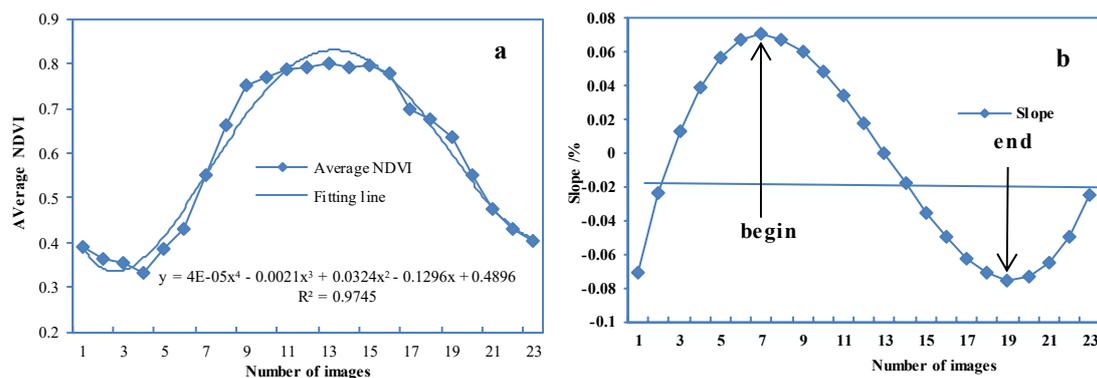


Figure 2. Average value and slope change curves of NDVI from 2000 to 2015

The variation of NDVI in the Qinling Mountains was in accordance with the quadratic polynomial fitting curve ($R^2 = 0.9745$) (Figure 2a). The first order derivative of the polynomial yields the slope of the polynomial fitting curve (Figure 2b). The two turning points of the slope are the beginning and the end of the vegetation growth season. The vegetation growth season in the Qinling Mountains began in early April (7th image, average NDVI value of 0.5509) and the end of middle October (19th images, average NDVI value of 0.6365), represented by a total of 13 images.

Based on the vegetation growth season, the inter-annual and seasonal NDVI values of the Qinling Mountains were obtained as follows: (1) Using the arithmetic mean method to merge the 16 d images by month, the monthly NDVI images were obtained from 2000 to 2015. (2) The vegetation growth season was divided into spring (months 4-5), summer (months 6-8) and autumn (months 9-10). Based on the monthly NDVI images, inter-annual and seasonal NDVI images were obtained by the Maximum Value Composition (MVC) method.

3.2. Temporal changes of inter-annual and seasonal NDVI

3.2.1. Temporal changes of Inter-annual NDVI. From 2000 to 2015, the NDVI of the Qinling Mountains was increasing year by year, among which the NDVI was the highest in 2014 (0.7639), and it was the lowest in 2000 (0.6039). The regression analysis was carried out by using NDVI as the dependent variable (y) and the year as the independent variable (x). The regression equation was $y = 0.0058x + 0.6742$ ($R^2 = 0.4869$), which shows that the linear growth rate of NDVI was 0.0058/a ($P < 0.01$) (Figure

3a). The results reflected that the inter-annual and seasonal vegetation was gradually improved in the Qinling Mountains.

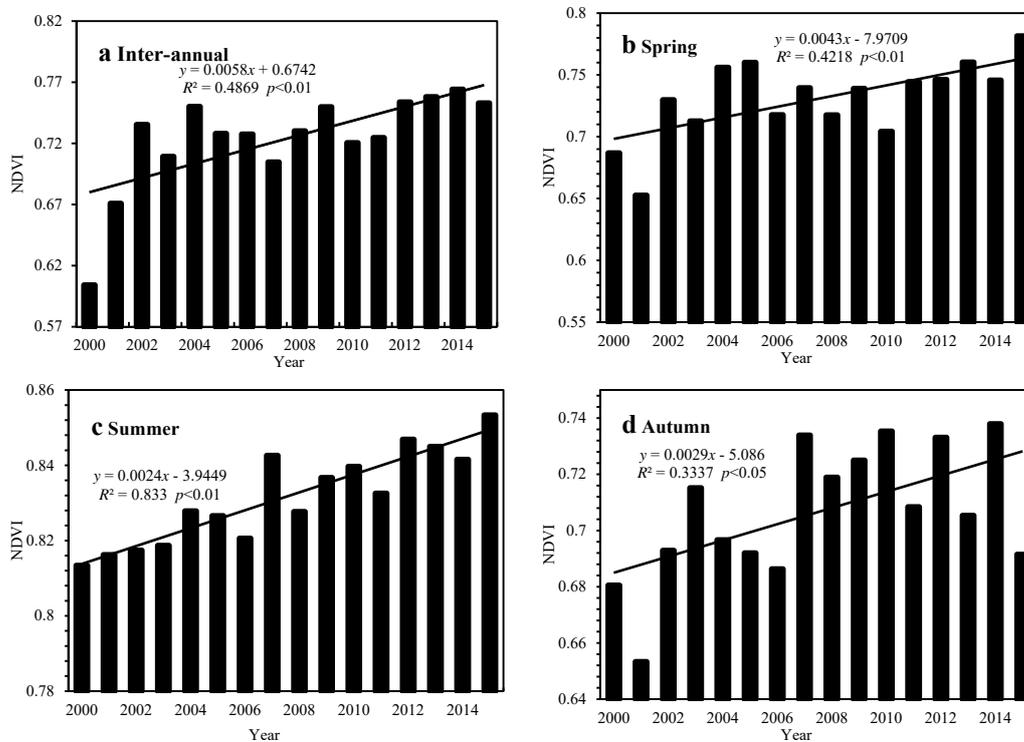


Figure 3. Change trends in annual and seasonal NDVI

3.2.2. Temporal changes in seasonal NDVI. The NDVI in the Qinling Mountains showed a significant inter-annual and seasonal growth process through the analysis of the change process, change trend and linear change rate of the NDVI. From 2000 to 2015, the average inter-annual, spring, summer and autumn NDVI values were 0.6839, 0.7168, 0.8332 and 0.6955, respectively (Figure 3b, c, d), which indicated that the NDVI of the Qinling Mountains was relatively high and that the vegetation cover was good. At the same time, the summer NDVI was higher than in spring and autumn, and the autumn NDVI was higher than the annual value, which reflected that the summer NDVI contributed the most to the inter-annual NDVI, followed by the spring and autumn NDVI data.

The linear growth rates of the inter-annual, spring, summer and autumn NDVI were 0.0058/a, 0.0043/a, 0.0024/a and 0.0029/a, respectively (Figure 3b, c, d). The results showed that the linear growth rate in spring contributed the most to the inter-annual NDVI, followed by autumn and summer. The above analysis indicated that the best water and temperature conditions occurred in the Qinling Mountains in summer (associated with the highest NDVI value) and that climate change did not have a significant effect on the summer vegetation, so the NDVI was relatively small and the growth rate was small. However, climate change, especially in spring and autumn, had a substantial effect on the spring and autumn NDVI, and the growth rate was higher.

3.3. Spatial changes in inter-annual and seasonal NDVI

3.3.1. Spatial changes in inter-annual NDVI. Spatial changes in NDVI in the Qinling Mountains were analyzed by the linear trend method. The positive and negative values of the change rate (a) reflect the linear increase and decrease in NDVI, and the magnitude of the absolute value of a reflects the rate of change. The results are shown in Figure 4.

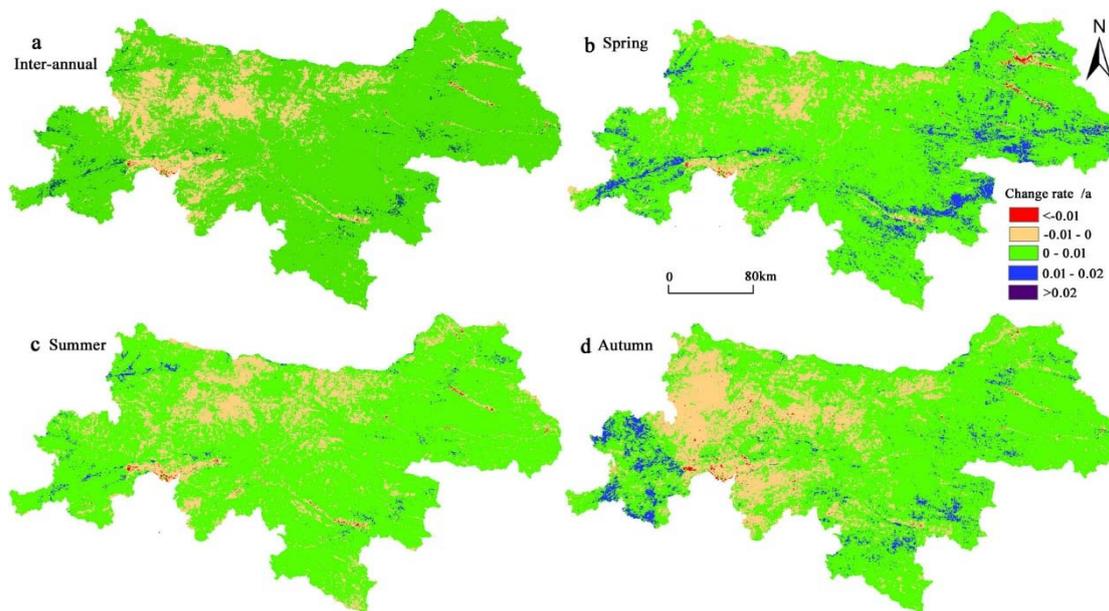


Figure 4. Spatial change trends in annual and seasonal NDVI between 2000 and 2015

The inter-annual NDVI in the Qinling Mountains mainly had an increasing trend ($a > 0$), but the growth rate was small, so the area with a value in the range of $0 - 0.01/a$ was the largest, while the area with a value above $0.01/a$ was small. The area with high growth rates was mainly distributed in the edge of the region, such as the eastern edge and the southwestern edge. The region of linear decrease ($a < 0$) was obvious, and the growth rate was mainly in the range of $-0.01/a$ to 0 . The area with decreasing NDVI was located in the middle and high altitude areas of the middle and west region, the Hanzhong basin of the southwest region, the Shangluo Basin of the northeast region and the Ankang Basin of the southeast region. Those areas had more intensive human activities (Figure 4a).

3.3.2. Spatial changes of seasonal NDVI. The spatial analysis of inter-annual and seasonal NDVI reflected that the NDVI in the Qinling Mountains was mainly increased from 2000 to 2015. The area of reduced NDVI was also large, and it was mainly distributed in the middle and high areas of the middle and west region, as well as the Hanzhong basin, the Shangluo basin and Ankang basin, which had intensive human activity. At the same time, it could be seen that the NDVI in the intensive human activities region higher reduction rate, and the middle and high altitude region had lower reduction rates. The reason for this may be related to driving factors. The former was driven by human activities, such as urban expansion that significantly reduced the rate of vegetation coverage. The latter may be driven by climate change, which can be identified by the distribution. The region driven by human activities was distributed in the river valleys, which was in the line with the expansion of human activities, such as the city. The reduction area of middle and high altitude was mainly covered large continuous surfaces, which was more in line with the action of large scale factors such as climate.

4. Conclusion

Based on the MODIS NDVI images from 2000 to 2015, the spatial and temporal variation characteristics of the NDVI in the Qinling Mountains were analyzed by the linear trend method and vegetation growth season extraction. The results showed that:

(1) The NDVI in the Qinling Mountains was higher and the vegetation cover was generally better, and the inter-annual and seasonal NDVI both significantly increased. The NDVI value in summer made the largest contribution to the annual value, followed by spring and autumn. The linear growth rate in both inter-annual and seasonal NDVI showed a linear growth trend, and the spring growth rate had the greatest contribution to the annual linear growth rate, followed by autumn and summer.

(2) The spatial change trend in both inter-annual and seasonal NDVI in the Qinling Mountains mainly increased, but the linear reduction area was also larger. The linear reduction area was mainly distributed

in the middle and high altitude areas of the central and western regions, as well as the Hanzhong basin, the Shangluo basin and the Ankang basin, where human activities were intensive. Driven by human activities, the NDVI in densely populated areas was higher than that in the middle and high altitude areas, where it may be driven by climate change.

The Qinling Mountains represent the transition zone between warm temperate and subtropical climates, and the vegetation growth is enhanced due to the abundant water and favorable temperature conditions. However, vegetation in the Qinling Mountains showed improvement, but the area of decreasing vegetation was also larger, which should receive more attention. The area of decreasing NDVI could be divided into two types: where it is driven by climate change and where it is driven by human activities. The former was not possible to change by policy adjustment, and the research on regional ecological response to climate change should be strengthened, whereas the latter could be achieved by limiting human activities.

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