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Analysis of Spatio-temporal Variation of Fractional Vegetation Coverage and Influence Factors in Qinghai, China

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ABSTRACT

The fractional vegetation coverage (FVC) can visually represent ecological changes in a region. Based on MDO12A1 data to calculate FVC, we investigated the spatial and temporal variations of FVC in Qinghai Province from 2001 to 2015 and performed correlation analysis with the annual mean temperature and annual rainfall. The results indicate that the spatial changes in FVC in Qinghai Province increase gradually from northwest to southeast and are discontinuous due to topographic variations. In Qinghai Province, the area of higher FVC decreased by 0.69% over the past 15 years, while the area of medium FVC increased by 5.75%, and the area of lower FVC decreased by 5.06%. Changes in FVC in Qinghai Province are influenced by changes in rainfall and temperature. The average partial correlation coefficients of FVC with rainfall and temperature are 0.031 and 0.117, respectively, indicating that rainfall has a more significant influence on vegetation growth when the temperature remains constant.

Contribution/Originality: This study investigated the influence of climatic factors on vegetation change in Qinghai Province over 20 years using partial correlation analysis. This study documents that partial correlation analysis has significant advantages when dealing with multiple influencing factors and provides reliable information for future ecological research.

1. Introduction

Vegetation cover is one of the most fundamental components of the terrestrial ecosystem; its increase or decrease affects the entire biosphere, and the migration of vegetation cover will directly impact the quality of life and health of humans. The variation in vegetation cover can visually represent the migration of vegetation zones and the increase or decrease of vegetation zones. Fractional vegetation coverage (FVC) is typically defined as the ratio of the vertical projection of vegetation (including leaves, stems, and branches) to the total area of a statistical area (Gitelson et al., 2002), which quantitatively depicts the degree of vegetation cover and contributes significantly to the atmosphere, pedosphere, hydrosphere, and biosphere (Gao et al., 2020). It is also one of the sensitive parameters for ecological changes and a crucial parameter in numerous models, such as those for predicting climate and soil erosion (Zhongming et al., 2010; Wang et al., 2015). Consequently, estimating FVC at regional and global scales is crucial to studying vegetation and related fields (Liu et al., 2019). The northeastern part of Qinghai Province is the Qilian Mountains, an essential water-conserving area in the northwestern arid region, and the southern part is known as the "Chinese Water Tower" (the source catchment area of the Yangtze, Yellow, and Lancang Rivers) (Xue et al., 2022). Changes in vegetation in this region will directly impact its capacity to conserve water, and the study of vegetation changes in this region can directly reflect the altering ecosystem characteristics in this region.

2. Data and Methods

2.1. Overview of the study area

The province of Qinghai is situated in the northeastern portion of the Tibetan Plateau, spanning 89° 35′ E to 103° 04′ E from west to east and 31° 40′ N to 39° 19′ N from south to north, with an average altitude of more than 3000 m above sea level. This region contains Qinghai Lake, the largest saltwater lake in China's interior. The Yangtze River, Yellow River, and Lancang River originate in Qinghai province (Feng et al., 2016).

The study area is influenced by the climate of the Qinghai-Tibet Plateau and desert climate, with long winters and short summers, large diurnal temperature differences, and little rainfall and concentration in summer, which is characteristic of continental plateau climate. The annual rainfall in the region ranges from 50 to 450 mm. The annual temperature ranges between -5.7°C and -8.5°C. The majority of Qinghai Province is dominated by plateaus interspersed with river valleys and basins. The terrain gradually rises from east to west (Tao et al., 2015).

2.2. Data sources and pre-processing

The remote sensing data were obtained from the International Scientific Data Mirror website of the Computer Network Information Center of the Chinese Academy of Sciences. The MODIS data were chosen from the MDO13A1 data of h25v5 and h26v5 images from 2001-2015, with a temporal resolution of 16 days and a spatial resolution of 500×500 m. The meteorological data were obtained from the Resource and Environment Science Data Center of the Chinese Academy of Sciences, which supplied national annual rainfall and annual average temperature data from 2001 to 2015. In order to obtain the annual rainfall and annual mean temperature data for the study area from 2001 to 2015, we first projection transform and resample the data using ArcGIS software to the exact 500 m resolution as the previous data. Next, we use the study area's vector boundary for uniform cropping.

We used ArcGIS software to reproject and format the downloaded MDO12A1 data, convert the format to TIFF format, convert the projection to WGS 84/Albers Equal Area Conic projection, and spatially mosaic the data. We then utilized the Maximum Composite Method to obtain month-by-month NDVI data (MVC). The DEM digital elevation data were selected from the SRTMDEM raw elevation data with a 90 m resolution; the reprojection and format conversion were performed in the preceding order using ArcGIS software, and the resolution was then resampled to 500 m. Using the model builder in ArcGIS, the NDVI and DEM data were uniformly cropped with the study area boundary map.

2.3. Fractional Vegetation Coverage (FVC)

There is a highly significant linear correlation between FVC and NDVI. The FVC is usually extracted directly by establishing the conversion relationship between the two in the study (Gutman et al., 1998). The current pixel dichotomy model is widely used to estimate FVC. It is based on the assumption that the NDVI value of each image element is synthesized from vegetation and soil, and its equation (1) is as follows (Carlson, et al., 1997).

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \qquad (1)$$

FVC represents the FVC of the study area; NDVI represents the normalized vegetation index of the study area; $NDVI_{soil}$ represents the normalized vegetation index of pure soil pixels in the study area; and $NDVI_{veg}$ represents the normalized vegetation index of pure vegetation pixels in the study area. In determining $NDVI_{soil}$ and $NDVI_{veg}$, the 5% confidence interval of the cumulative *NDVI* frequency table was deemed to represent the pure soil pixel. In comparison, the 95% confidence interval represented the pure vegetation pixel.

2.4. Fractional Vegetation Coverage (FVC)

In this study, the slope analysis method was applied to each pixel to determine the trend of FVC change in each year from 2001 to 2015. It can reflect the spatial distribution characteristics of FVC variations over time in the study area, and its equation (2) is:

$$\theta_{slope} = \frac{n \times \sum_{i=1}^{n} i \times FVC_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} FVC_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \qquad (2)$$

Where θ_{slope} is the slope of the changing trend, $\theta_{slope} > 0$ demonstrates that the change of FVC in the region has increased over the past n years. In contrast, $\theta_{slope} < 0$ indicates that the change in FVC over n years is decreasing; n represents the monitoring period (year), and FVC_i is the FVC in the ith year. Based on simulation results, seven change ranges were defined in this study: significant decrease, moderate decrease, slight decrease, no change, a slight increase, moderate increase, and significant increase.

2.5. Correlation analysis method

This paper analyzes the bias correlation between FVC and each climate factor using pixel-based spatial analysis. After calculating the single correlation coefficients, the partial correlation coefficients are obtained. The correlation coefficients of the FVC with temperature and rainfall are calculated using the following equation (3) (Chen et al., 2016):

$$Rxy = \frac{\sum_{i=1}^{n}[(x_i - \bar{x})(y_i - \bar{y})]}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (3)$$

Where, R_{xy} is the correlation coefficient between x and y, x_i is the FVC in the ith year, y_i is the annual mean temperature or annual rainfall in the ith year, $\bar{x}$ is the mean of FVC over the years, $\bar{y}$ is the mean of temperature or rainfall over the years, and i is the sample size.

The partial correlation coefficients of FVC based on rainfall with temperature and those of FVC based on temperature with rainfall were calculated as follows: (4) (Mark et al., 1984).

$$r_{123} = \frac{r_{12} - r_{13} r_{23}}{\sqrt{(1 - r_{13}^2) + (1 - r_{23}^2)}} \quad (4)$$

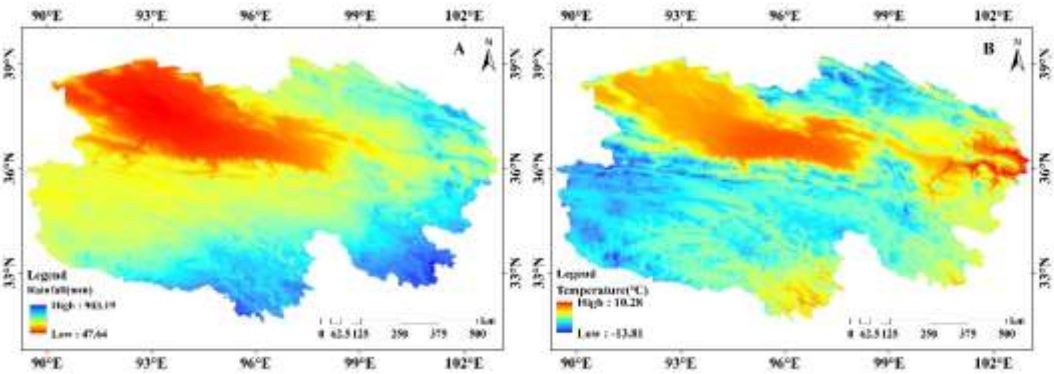
Where r_{123} is the partial correlation coefficient between variables 1 and 2 when variable 3 is constant. r_{12}, r_{23}, and r_{13} represent the correlation coefficients between variables 1 and 2, 2 and 3, and 1 and 3, respectively.

3. Results and Discussion

3.1. Spatial distribution characteristics of annual rainfall and mean annual temperature in Qinghai Province

The spatial distribution of the annual mean temperature and annual rainfall in Qinghai Province from 2001 to 2015, with an average annual rainfall of 400.95 mm over 15 years (Figure 1). It was determined that 52.71% of the study area receives an average annual rainfall of 400 mm or more, the regions with the lowest rainfall are located in the northwest, primarily in the Chaidamu Basin. The average annual temperature is -0.38°C. The overall rainfall trend is from northwest to southeast, with a minimum of 47.64 mm and a maximum of 903.19 mm (Fig. 1A); the annual mean temperature ranges between a high of 10.28°C and a low of -13.81°C. (Fig. 1 B). The mean annual rainfall and mean annual temperature in the study area exhibit significant spatial variability; the mean annual rainfall and mean annual temperature exhibit opposite relationships, and both are strongly correlated with elevation.

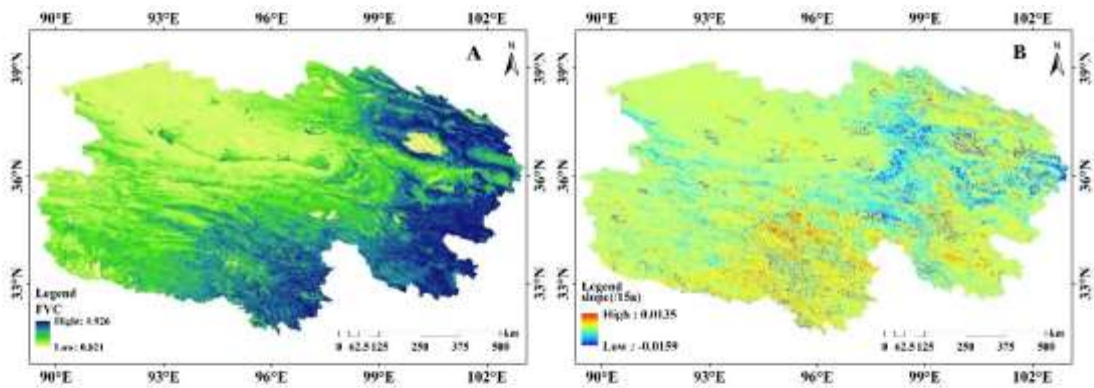
Figure 1: Spatial changes in annual average rainfall (A) and mean annual temperature (B) in Qinghai Province, 2001-2015



3.2. Spatial and temporal variation characteristics of FVC

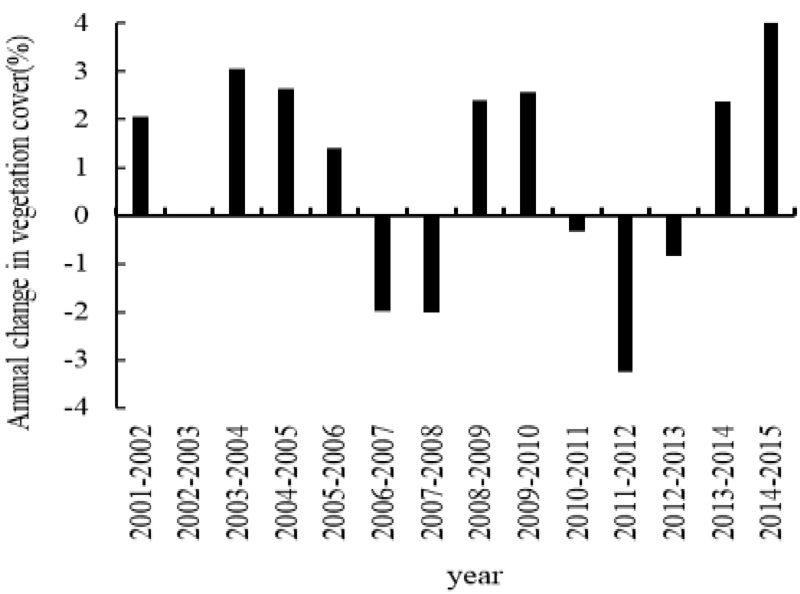
Changes in the average FVC in Qinghai Province from 2001 to 2015 illustrate a general trend of low FVC in the northwest and high FVC in the southeast, with an average FVC of 0.393 (Figure 2A). The Chaidamu Basin is located northwest of the study area, where rainfall is low, and the soil is predominantly sandy, resulting in low FVC and an average FVC of 0.12 in this region. Sanjiangyuan National Nature Reserve is located in the southeastern portion of the study area, where there are numerous rivers, lakes, and marshes, as well as an abundance of water, so the FVC is good, and the average FVC is above 0.6. The inter-annual variation in FVC reflects the change in surface vegetation cover in the area (Figure 2B), with the red area representing an increase in FVC values of 21.4% and the blue area representing a decrease of 35.2%.

Figure 2: Spatial distribution of mean FVC from 2000-2015 (A), interannual variation of FVC from 2000-2015 (B)



The interannual variation of FVC mean values in Qinghai province from 2001 to 2015 is depicted (Figure 3).

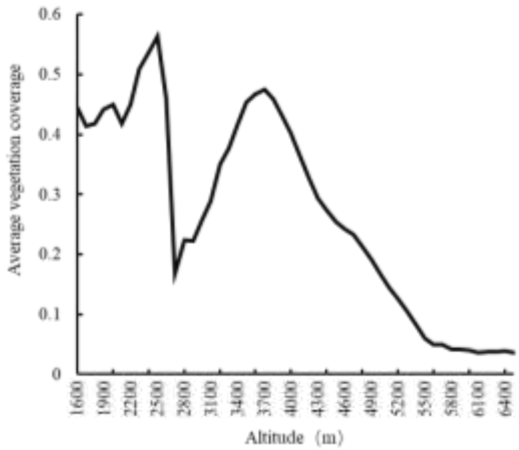
Figure 3: Variation in annual mean FVC values



The average FVC decreased in individual years and showed an overall increasing trend, in five of the years, the average FVC was lower than the previous year, with the most significant decrease occurring in 2011-2012, at 3.233%. The FVC increased in the other years, with the biggest increase being 0.4415 % for 2014–2015.

The variation in FVC with altitude is depicted in the graph (Figure 4), with the area below 2500 m increasing with altitude. The FVC decreases rapidly in the area between 2500-3000 m. Within this altitude range is the Chaidamu Basin, which has a plateau continental climate dominated by aridity. The arid desert and sparse vegetation dominate the natural landscape, and annual rainfall ranges from 200 mm in the southeast to 15 mm in the northwest. In the altitude range of 3000–3700 m, FVC increases with increasing altitude. Between 3700-5800 m FVC gradually decreases with increasing altitude, the area above 5800m FVC is extremely low, and the surface is covered by bare rock, bare soil, or snow and ice.

Figure 4: FVC variation with altitude



In this study, FVC was classified according to the Soil Erosion Classification and Grading Standard into three classes (Table 1). High FVC in 2001 compared to 2015 changed from 27.64% to 26.95%, a transformation of -0.69%. Medium grade FVC in 2001 compared to 2015 changed from 24.81% to 30.56%, a transformation of 5.75%. Low grade FVC in 2001 compared to 2015 changed from 47.55% to 42.49%, a transformation of -5.06%. The data above reveal that low-grade FVC dominates, with an area share of more than 40%, and based on the change in the area of the three grades of FVC, the area of low-grade decreases, high grade decreases, and medium grade increases.

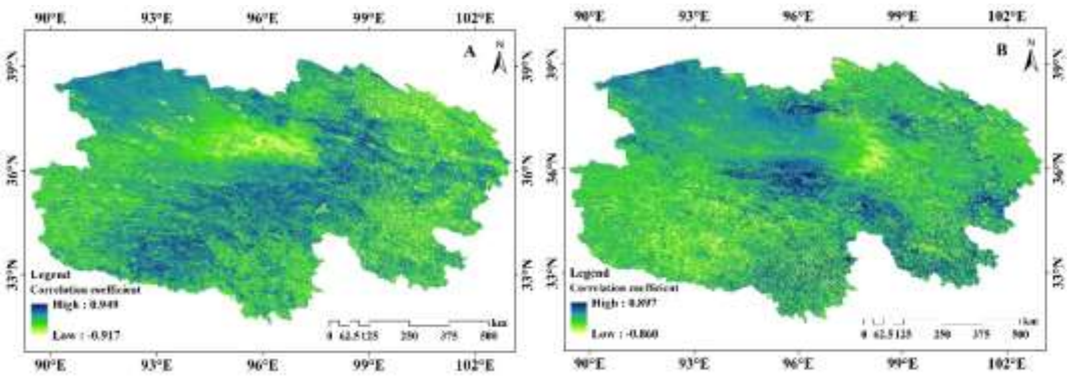
Table 1: Changes to the various fraction vegetation coverage (FVC) classes in Qinghai Province

FVC (%)	FVC class	Area percentage (%)		Conversion volume (%)
		2001	2015	
＜30	Low grade FVC	47.55	42.49	-5.06
45-60	Medium grade FVC	24.81	30.56	5.75
＞60	High grade FVC	27.64	26.95	-0.69

3.3. Correlation analysis of vegetation coverage and climate factors

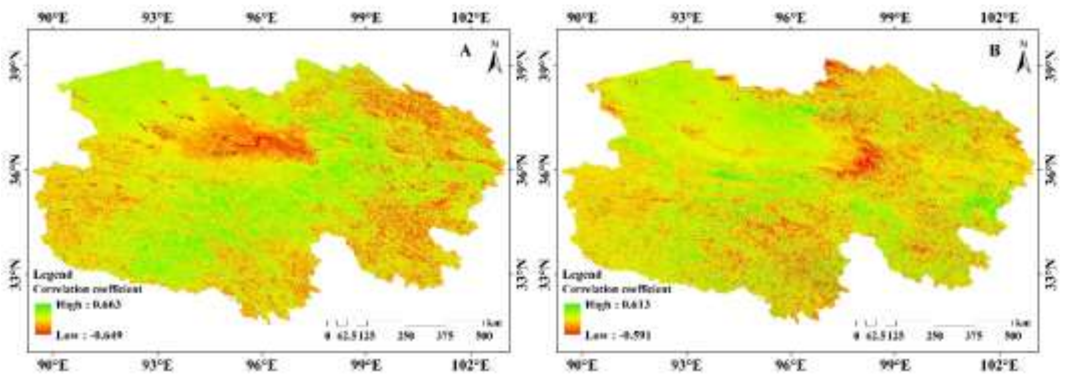
During 2001–2015, the correlation coefficients between FVC and annual rainfall and mean annual temperature were calculated separately for each pixel in the study area. Significant spatial variation existed in the response of FVC changes to temperature and rainfall in various regions (Figure 5). Greater absolute values of the correlation coefficients indicate stronger correlations between changes in FVC and climatic factors, whereas smaller absolute values indicate weaker correlations (Wang et al., 2018). In the study area, the average correlation coefficients of FVC with annual rainfall and mean annual temperature were 0.239 and 0.081, respectively, and the area with a positive correlation between FVC and annual rainfall comprised 81.45% of the study area, and the area with a positive correlation between FVC and mean annual temperature comprised 67.86% of the study area.

Figure 5: Correlation analysis between FVC and rainfall (A), correlation analysis between FVC and temperature (B)



This study employs a partial correlation coefficient to investigate the FVC with annual rainfall and annual mean temperature. This analysis has the advantage of eliminating the effect of annual mean temperature when analyzing the correlation between annual rainfall and FVC. Consequently, when there are multiple influences, a partial correlation analysis can be used to examine the impact of specific significant factors (Figure 6).

Figure 6: Partial correlation analysis of FVC with rainfall (A), Partial correlation analysis of FVC with temperature (B)



In the study area, the average partial correlation coefficients between the FVC and the annual rainfall and annual mean temperature were calculated to be 0.031 and 0.117, respectively. There was a positive correlation between FVC and annual rainfall in 80.79% of the study area, and between FVC and annual mean temperature in 69.92% of the study area. This suggests that the correlation between FVC and annual mean temperature is generally stronger along the study area. This demonstrates that temperature changes have a greater impact on vegetation growth in Qinghai Province, which is located at a high altitude and is mostly mountainous. This finding is consistent with the findings of Wu (2015).

Changes in FVC in Qinghai Province are attributable to a combination of natural and anthropogenic factors, and monitoring vegetation change is a dynamic, long-term process (Song et al., 2007). In this paper, we analyze the changes in the study area over the past 15 years by calculating FVC data. Due to the characteristics of MODIS data, there are deficiencies and areas for improvement, such as the short time series of MODIS data, which can be combined with other satellite data to extend the time series to study the changes in FVC on a larger scale in future research. In this paper, only the effect of climatic factors on FVC is examined; the effect of human activities on FVC is not considered. Future research will therefore focus on the characteristics and causes of NDVI changes in various vegetation types, as well as the response of cover changes in various vegetation types to temperature, rainfall, humidity, soil, and human activities.

4. Conclusion

The spatial characteristics of fractional vegetation coverage (FVC) in the study area were calculated using MODIS NDVI data and combined with rainfall and temperature data, as well as DEM data, from 2001 to 2015 to investigate the spatial and temporal changes in FVC on Qinghai Province over the past 15 years, and the following conclusions were drawn:

i. The overall FVC in Qinghai Province was relatively low from 2001 to 2015, with the area of low FVC accounting for 47.55% in 2001 and 42.49% in 2015. Moreover, the area of the high FVC decreased by 0.69% in 2015 compared with 2001, and the area of the medium FVC increased by 5.75%.
ii. The spatial variation trend of FVC in Qinghai Province increases gradually from northwest to southeast, and the spatial distribution is primarily influenced by topography, temperature, and rainfall.
iii. The changes in FVC in Qinghai Province are influenced by the changes in rainfall and temperature; the average partial correlation coefficients of FVC with rainfall and temperature are 0.031 and 0.117, respectively, indicating that the changes in rainfall exert a greater influence on vegetation growth under the same temperature conditions.

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Conflict of Interest

The authors reported no conflicts of interest for this work and declare that there is no potential conflict of interest with respect to the research, authorship, or publication of this article.

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