Spatiotemporal Characteristics of Vegetation Coverage and Its Response to Climatic Factors in Southern Xinjiang over the Past 20 Years: A Case Study of Taxkorgan Tajik Autonomous County (Postprint)

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Abstract

Vegetation coverage is an evaluation indicator reflecting ecological environmental quality, and understanding its changes facilitates ecological civilization construction, regional agricultural and pastoral planning, and ecological environmental protection. Based on the Normalized Difference Vegetation Index (NDVI) from 2001 to 2020, taking cropland, forestland, and grassland vegetation types as research objects, vegetation coverage was calculated using the dimidiate pixel model, and spatiotemporal characteristics of vegetation coverage in Taxkorgan Tajik Autonomous County were analyzed using spatial stability analysis, Sen+Mann-Kendall spatial trend analysis, linear regression, and other methods; simultaneously, combining temperature and precipitation data, the influence of climatic factors on vegetation coverage was analyzed using Spearman correlation analysis, GIS spatial analysis, and other methods. The results show that: (1) Over the past 20 years, vegetation coverage was dominated by moderate vegetation coverage areas, with vegetation coverage decreasing by 4.79%. (2) The spatial stability of vegetation coverage exhibited minor fluctuations, dominated by fluctuating change (37.3%) and moderately fluctuating change (32.7%); areas showing significant decrease and non-significant decrease in vegetation coverage accounted for 3.8% and 54.5% of the total area, respectively. (3) The vegetation conditions of cropland, forestland, and grassland all exhibited slight degradation to varying degrees, with vegetation coverage decreasing by 4.57%, 6.32%, and 4.24%, respectively; in terms of spatial stability, non-significant decrease accounted for 51.28%, 54.48%, and 52.29%, respectively. (4) During 2001–2020, cropland demonstrated greater stability and slower degradation compared to forestland and grassland in terms of spatial stability and degradation degree, while forestland

degradation was more severe than that of cropland and grassland. In the study area, vegetation coverage showed minor changes with a weak declining trend, and human activities constitute the primary factor affecting vegetation growth.

Full Text

Temporal and Spatial Characteristics of Fractional Vegetation Coverage and Its Response to Climatic Factors in Southern Xinjiang in Recent 20 Years: A Case Study of Taxkorgan Tajik Autonomous County

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Abstract: Fractional vegetation coverage (FVC) is a critical indicator for evaluating ecological environmental quality. Understanding its dynamics is essential for ecological civilization construction, regional agricultural and pastoral planning, and environmental protection. Based on the Normalized Difference Vegetation Index (NDVI) from 2001 to 2020, this study examines cultivated land, forestland, and grassland vegetation types. The mixed pixel dichotomy model was employed to calculate FVC, and spatial stability analysis, Sen+Mann-Kendall spatial trend analysis, and linear regression methods were applied to analyze the spatiotemporal characteristics of FVC in Taxkorgan Tajik Autonomous County. Concurrently, temperature and precipitation data were integrated to assess climate impacts on FVC using Spearman correlation analysis and GIS spatial analysis. The results indicate: (1) Over the past two decades, FVC was predominantly concentrated in medium-coverage areas, with an overall decrease of 4.79%. (2) Spatial stability of FVC exhibited minor fluctuations, characterized by fluctuating changes (37.3%) and moderately fluctuating changes (32.7%). Areas with significant and non-significant FVC decreases accounted for 3.8% and 54.5% of the total area, respectively. (3) Vegetation conditions across cultivated land, forestland, and grassland showed varying degrees of slight degradation, with FVC decreasing by 4.57%, 6.32%, and 4.24%, respectively. In terms of spatial stability, non-significant decreases were 51.28%, 54.48%, and

52.29%, respectively. (4) Between 2001 and 2020, cultivated land demonstrated greater stability and slower degradation compared to forestland and grassland, while forestland degradation was more severe than that of cultivated land and grassland. Overall, FVC changes in the study area were minimal, showing a slight downward trend, with human activity identified as the primary factor influencing vegetation growth.

Keywords: dimidiate pixel model; fractional vegetation coverage (FVC); Sen+Mann-Kendall; spatial stability; climate factors

Introduction

Vegetation plays an indispensable role in terrestrial ecosystems, serving critical functions in preventing soil erosion, assessing ecological risks, and maintaining ecological balance. Fractional vegetation coverage (FVC), defined as the percentage of vertical projection area of vegetation (including leaves, stems, and branches) relative to the total statistical area, serves as a vital parameter for evaluating regional ecosystem security, environmental quality, and stability. It plays a significant role in reflecting ecological health and monitoring ecosystem changes, making it foundational data widely applied in climate, ecology, hydrology, and other research fields. Monitoring spatiotemporal vegetation changes is therefore crucial for regional ecosystem stability and optimization.

To quantitatively assess vegetation coverage dynamics and climate responses, scholars have conducted extensive research on Xinjiang’ s vegetation changes using GIMMS, SPOT-VGT, Landsat, and MODIS data. Cao Yongxiang et al. analyzed spatiotemporal vegetation changes and influencing factors in the Cele oasis-desert ecotone of Xinjiang using MODIS data, identifying human activity as the dominant factor. Sun Fan et al. investigated the spatiotemporal characteristics, trends, and climate responses of the “mountain-oasis-desert” vegetation system in Xinjiang using GIMMS NDVI3g data. Pang Ran et al. examined vegetation index changes and hydrothermal combination effects in the Turpan Basin, concluding that moisture conditions were the primary limiting factor for vegetation growth in most areas, while increased heat benefited vegetation development.

However, most remote sensing studies on FVC in Xinjiang have focused on larger administrative scales such as prefecture-level or provincial levels, with limited research on long-term FVC dynamics at the county level. Moreover, previous analyses of FVC changes have typically adopted a holistic perspective, neglecting the distinct dynamics of ecologically significant vegetation types and failing to parse differential responses among various vegetation types to climatic factors. Therefore, this study selects Taxkorgan Tajik Autonomous County (hereafter referred to as Taxkorgan County) as the research area, focusing on cultivated land, grassland, and forestland vegetation types. Based on the NDVI index, we constructed FVC image data using the mixed pixel dichotomy model and applied spatial stability analysis, Sen+Mann-Kendall spatial trend analysis, linear regression, and Spearman correlation analysis to explore vegetation dynamics, trend changes, and responses to climate change. The findings aim to provide data support for regional ecological maintenance, ecological management, and policy formulation.

[Figure 1: see original paper] shows the study area schematic diagram. Note: This map was produced based on the standard map downloaded from the Standard Map Service website of the Department of Natural Resources of Xinjiang Uygur Autonomous Region, with approval number GS(2020)182. The base map boundaries were not modified. The same applies below.

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1 Study Area Overview

Taxkorgan Tajik Autonomous County is located in southern Xinjiang (35°37 -38°40 N, 71°23 -77°01 E), covering an area of approximately 2.5\$×10^{4}\$ km^2, which accounts for 2.5% of Xinjiang’ s total area. The county occupies a unique geographical position described as “bordering three countries, connecting two Asian regions through two passes, and linking east and west via two routes.” Situated on the eastern Pamir Plateau with an average elevation above 4,000 m, the region is rich in glacier resources, with a total glacier area of approximately 2.3\$×10^{3}\$ km^2. Peaks exceeding 5,000 m remain snow-covered year-round, including K2 (8,611 m), the world’ s second-highest peak, in the south, and Muztagh Ata (7,546 m), the “Father of Glaciers,” in the north. The climate is characterized as a cold temperate hyper-arid desert climate with continental high-altitude mountain arid features, featuring an average annual temperature of 3.3°C and average annual precipitation of 69 mm. [Figure 1: see original paper] illustrates the study area.

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2 Data and Methods

2.1 Data Sources and Processing

NDVI data were obtained from NASA’s MOD13Q1 product (https://lpdaac.usgs.gov/) at 250 m spatial resolution, covering the period 2001-2020. The Maximum Value Composite (MVC) method was applied to minimize external environmental influences such as cloud shadows, aerosols, and solar zenith angle effects. Temperature and precipitation data were sourced from the China Meteorological Data Network (http://data.cma.cn/) for meteorological stations across Xinjiang. These point data were interpolated using the Inverse Distance Weighting (IDW) method to generate raster datasets matching the NDVI spatial resolution. Land use data for 2020 were obtained from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences (http://www.resdc.cn) at 1 km spatial resolution.

2.2 Methods

2.2.1 Fractional Vegetation Coverage (FVC) FVC was calculated using the mixed pixel dichotomy model, which assumes each pixel comprises soil and vegetation components. The formula is as follows:

$$FVC = \frac{NDVI - NDVI_S}{NDVI_V - NDVI_S}$$

where FVC is fractional vegetation coverage; $NDVI$ is the normalized difference vegetation index; $NDVI_V$ is the NDVI value for fully vegetated pixels; and $NDVI_S$ is the NDVI value for bare soil or non-vegetated pixels. Based on regional vegetation characteristics and the Technical Specification for Evaluation of Eco-environmental Status, FVC was classified into high vegetation coverage area (FVC $\geq$ 60%), medium vegetation coverage area (20% $\leq$ FVC $<$ 60%), low vegetation coverage area (5% $\leq$ FVC $<$ 20%), and bare land (FVC $<$ 5%).

2.2.2 Sen+Mann-Kendall Trend Analysis The Sen+Mann-Kendall method combines trend calculation with Mann-Kendall testing, enhancing noise resistance and improving accuracy in long-term trend analysis. The Sen' s slope estimator is calculated as:

$$\beta = \text{Median}\left(\frac{x_j - x_i}{j - i}\right), \quad 1 < i < j < n$$

where β represents the trend magnitude; x_i and x_j are data values at times i and j; and n is the number of samples. A negative β indicates a decreasing trend, while a positive value indicates an increasing trend.

The Mann-Kendall test statistic S is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i)$$

where sign is the sign function. For $n \geq 8$, S is approximately normally distributed with variance:

$$\text{Var}(S) = \frac{n(n-1)(2n+5)}{18}$$

The standardized test statistic Z is computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & S < 0 \end{cases}$$

At a given confidence level α, if $|Z| > Z_{1-\alpha/2}$, a significant trend exists.

2.2.3 Coefficient of Variation The coefficient of variation (C_v) was calculated at the pixel level to analyze interannual fluctuation patterns:

$$C_v = \frac{\sigma}{\mu}$$

where σ is the standard deviation and μ is the mean value of FVC over the time series. A smaller C_v indicates higher stability.

2.2.4 Correlation Analysis Spearman correlation analysis was employed to examine vegetation-climate relationships. The correlation coefficient between variables x and y is:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

where x_i represents monthly FVC values; y_i represents monthly temperature or precipitation; $\bar{x}$ and $\bar{y}$ are their respective means; and n is the sample size.

2.2.5 Linear Regression Linear regression analysis was used to study statistical relationships and long-term trends:

$$y = a + bx + \varepsilon$$

where y is the dependent variable (FVC); x is the time variable; a and b are constants; and ε is random error.

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3 Results

3.1 Spatiotemporal Characteristics of NDVI

During the growing season (April-October), NDVI showed clear interannual trends, fluctuating between 0.025 and 0.087. Notably, rapid increases began in April, peaking in August (0.087), then declining to low values through September-October. Overall, April-August represents the vigorous vegetation growth period. The growing season NDVI increased at a rate of $0.0008 \cdot \mathrm{a}^{-1}$ ($\mathrm{R}^2 = 0.12$), though this trend exhibited distinct phases: a faster increase from 2001-2010 ($0.0014 \cdot \mathrm{a}^{-1}$), followed by fluctuating increases after reaching a minimum in 2011.

Based on 2020 land use data, vegetation was classified into cultivated land, grassland, and forestland. Grassland dominated, accounting for 36.56% of the total area, while cultivated land and forestland comprised only 0.14% and 0.02%, respectively. Despite area differences, all vegetation types showed consistent trend fluctuations (increasing at $0.0009 \cdot a^{-1}$), though forestland and grassland increased more slowly than cultivated land ($0.008 \cdot a^{-1}$). Maximum NDVI values appeared in forestland, while minimum values occurred in cultivated land.

3.2 Spatiotemporal Characteristics of Fractional Vegetation Coverage

Using growing season MODIS NDVI data, we calculated FVC for Taxkorgan County. The results show that over the past 20 years, FVC decreased by 4.79%, with medium-coverage areas predominating (exceeding 29.8% of the total area). Different FVC classes exhibited distinct spatiotemporal patterns: high-coverage areas showed trends similar to overall NDVI but differed from medium- and low-coverage areas. High-coverage areas improved at $0.0035 \cdot a^{-1}$, while medium- and low-coverage areas degraded at $0.0183 \cdot a^{-1}$ and $0.0056 \cdot a^{-1}$, respectively.

Spatial stability analysis revealed that relatively low fluctuation changes and moderate fluctuation changes dominated, accounting for 37.3% and 32.7% of the total area, respectively. Relatively low fluctuations were concentrated in high- and medium-coverage areas, moderate fluctuations mainly occurred in low-coverage areas, and high fluctuations appeared at boundaries between low- and medium-coverage areas.

Spatial trend analysis using Sen+Mann-Kendall indicated slight ecological degradation. Areas with significant FVC decreases accounted for 3.8% of the total area, while non-significant decreases comprised 54.5%. High-coverage areas constituted 12.0% of the region, medium-coverage areas 12.8%, and low-coverage areas 54.48%.

Analyzing different vegetation types, all showed slight degradation over the 20-year period. Cultivated land, forestland, and grassland FVC decreased by 4.57%, 6.32%, and 4.24%, respectively. Spatial stability analysis showed non-significant decreases of 51.28%, 54.48%, and 52.29%, respectively. Cultivated land exhibited more stable and slower degradation compared to forestland and grassland, while forestland degradation was more severe than that of cultivated land and grassland.

3.3 Impacts of Temperature and Precipitation on Fractional Vegetation Coverage

Climate change is a primary driver of regional vegetation dynamics, with precipitation and temperature being the most direct and sensitive factors. Spearman correlation analysis between growing season FVC and monthly precipitation/temperature revealed that precipitation had minimal impact on most areas, showing weak positive correlations only in limited regions (2.92% of total area). Taxkorgan County is extremely arid, with average monthly precipitation of only 7.3 mm, limiting vegetation impact.

Temperature showed weak positive and negative correlations with FVC (correlation coefficients ranging from -0.40 to 0.41), affecting 0.18% and 1.91% of the area, respectively. The region' s abundant glaciers and permanent snow cover mean that temperature increases promote meltwater, providing irrigation resources for vegetation in some areas. However, elevated temperatures also intensify evapotranspiration, inhibiting plant growth.

[Figure 5: see original paper] presents the correlation analysis between FVC and climate factors.

4 Discussion

The slight decline in FVC observed in this study, where degraded areas slightly exceed improved areas, aligns with findings from other arid region studies. While the government has implemented robust ecological measures to increase grassland area, regional animal husbandry remains extensive, prioritizing quantity and scale expansion, which creates prominent grassland-livestock conflicts. Rapid tourism development, increasing visitor numbers, and expanding construction land have also contributed to FVC decline. Population growth, economic development needs, and urbanization have intensified pressure on natural resources and the environment.

Although this study examined FVC spatiotemporal characteristics and correlations with temperature and precipitation—providing scientific significance and reference value for ecological construction—certain limitations exist. While climate change and human activity are primary drivers of vegetation change, this study focused primarily on climate impacts. Other factors such as groundwater, topography, soil moisture, temperature, and nutrients also significantly influence FVC and warrant consideration in future research.

5 Conclusions

Based on MODIS NDVI data, temperature, and precipitation data from 2001-2020, this study employed the mixed pixel dichotomy model, linear trend analysis, coefficient of variation, Sen+Mann-Kendall trend analysis, and correlation analysis to examine FVC spatiotemporal patterns in Taxkorgan County and their response to climatic factors. The main conclusions are:

1) Fractional vegetation coverage decreased by 4.79% over the past 20 years, with medium-coverage areas dominating. Medium- and low-coverage areas degraded at rates of $0.0183 \cdot a^{-1}$ and $0.0056 \cdot a^{-1}$, respectively, while high-coverage areas improved at $0.0035 \cdot a^{-1}$.
2) Spatial stability was characterized by relatively low fluctuation (37.3%) and moderate fluctuation (32.7%). Relatively low fluctuations were con-

centrated in high- and medium-coverage areas, while moderate fluctuations occurred mainly in low-coverage areas and at boundaries between low- and medium-coverage areas.

3) The spatial trend showed slight degradation, with significantly decreasing areas accounting for 3.8% of the total area and non-significantly decreasing areas comprising 54.5%.
4) Cultivated land, forestland, and grassland FVC decreased by 4.57%, 6.32%, and 4.24%, respectively. Spatial stability showed non-significant decreases of 51.28%, 54.48%, and 52.29%, respectively. Cultivated land demonstrated greater stability and slower degradation than forestland and grassland, while forestland experienced more severe degradation than cultivated land and grassland.

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