Postprint of Spatiotemporal Patterns of Vegetation Cover in the Tarim River Basin, 2000-2018

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Abstract

Using MODIS-NDVI data from 2000 to 2018, and employing methods such as Sen + Mann-Kendall trend analysis, coefficient of variation, Hurst exponent, partial correlation analysis, and residual analysis, this study analyzed the spatiotemporal patterns of vegetation cover and the impacts of climatic factors and human activities on vegetation changes in the Tarim River Basin. The results show that: (1) Vegetation cover in the Tarim River Basin showed an overall significant increasing trend, with 2008 serving as a turning point marking distinct stage-based changes. (2) Vegetation distribution exhibited significant regional differences, characterized by "higher in the north and lower in the south, higher in the west and lower in the east", with high vegetation cover areas distributed in mountainous regions, oases, and oasis-desert ecotones. (3) Across the region, the vegetation cover trend was predominantly stable. In high vegetation cover areas such as mountainous regions, vegetation activity showed significant responsiveness. Most areas in the region will maintain their existing stable trends. (4) The combined influence of temperature and precipitation on NDVI gradually increased from northeast to southwest, with precipitation exerting a more pronounced effect on NDVI. Areas where human activities exerted positive impacts on vegetation changes were mainly distributed in oases, oasis-desert transition zones, and the lower reaches of the Tarim River.

Full Text

Spatiotemporal Variations of Vegetation Coverage in the Tarim River Basin from 2000 to 2018

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Abstract

The ecology of the Tarim River Basin in Xinjiang, China is relatively fragile. During the past few decades, unreasonable development and utilization have resulted in serious damage to vegetation coverage. However, due to the implementation of ecological comprehensive management projects in the Tarim River Basin and recent climate change, the temporal and spatial distribution of vegetation in the basin has undergone certain changes. Clarifying the relationship between vegetation coverage change and climate change, as well as human activities, can provide a scientific reference for ecological maintenance and management in the Tarim River Basin.

Based on MODIS-NDVI data and using the Sen+Mann-Kendall trend analysis, coefficient of variation method, Hurst index, partial correlation analysis, and residual analysis, this study analyzed the temporal and spatial change characteristics and sustainability of vegetation coverage in the Tarim River Basin from 2000 to 2018 and investigated and distinguished the range and extent of impacts of temperature and precipitation climatic factors as well as human activities on vegetation coverage changes. The results are summarized as follows: (1) The level of vegetation coverage in the Tarim River Basin has increased significantly with clear stage changes. The vegetation changes varied from an increasing trend to a decline before 2008 and then increased rapidly. The vegetation increase is mainly concentrated in Korla, Yanqi, Aksu, Kuqa, Kashgar, and the region of the central Tianshan Mountains. The vegetation variation near the Kuluk Tagh Mountains is relatively small. (2) More strongly affected by regional geomorphologic patterns, the vegetation coverage of the Tarim River Basin in the north is greater than that in the south, and the vegetation coverage in the west is greater than in the east. The area of relatively high vegetation coverage is distributed in mountainous areas, oasis areas, and the oasis-desert interlaced zone. In addition, the basin vegetation is distributed along the river, shaped as a strip. (3) The vegetation coverage trend in the Tarim River Basin is mostly unchanged (50.80%) and the improved trend area (37.97%) is mainly concentrated in the oasis with abundant water resources in the basin. The stability of vegetation coverage in the Tarim Basin is in a state that "the outside of the basin is higher than the inside and high and low fluctuations coexist and the moderate fluctuation is mostly" . The response of vegetation activity is significant in areas covered with high vegetation amounts such as mountainous areas. Most regions in the study area will maintain the existing stable trend. The area of unsustainable vegetation coverage change (30.83%) is mainly distributed in mountainous areas and water systems and the sustainable area (69.17%) is mostly concentrated in oasis, oasis-desert interlaced zone, and desert area. (4) The NDVI in the Tarim River Basin has a significant negative correlation with temperature in most areas (72.92%). The NDVI is positively correlated with precipitation in most areas (82.48%). The combined effects of temperature and precipitation on the NDVI gradually increase from northeast to southwest and the impact of precipitation on the NDVI is more significant. The areas where human activities have positive effects on vegetation change are mainly distributed in the oasis, oasis-desert transition zone, and the lower reaches of the Tarim River. In areas with relatively low human activity such as deserts and mountainous areas, the NDVI residual is also affected by other linear factors of continuous change.

Keywords: vegetation coverage; spatiotemporal variations; climatic factor; human activity; Tarim River Basin

1. Methods

1.1 Data Source

This study utilized MODIS-NDVI data from 2000 to 2018, obtained from the Earth Observing System Data and Information System (EOSDIS). The MOD13Q1 product was used, with a temporal resolution of 16 days and spatial resolution of 250 m. The MRT (MODIS Reprojection Tool) was employed for data preprocessing, including projection transformation and format conversion.

1.2 Sen+Mann-Kendall Trend Analysis

The Sen+Mann-Kendall method was used to analyze the temporal trend of NDVI. The Sen slope estimator calculates the median slope between all pairwise combinations of points:

$$\text{Sen} = \text{median}\left(\frac{NDVI_j - NDVI_i}{j - i}\right) \quad \text{for } 1 < i < j < n$$

where $NDVI_i$ and $NDVI_j$ are the NDVI values at times i and j, respectively, and n is the number of time periods. A positive Sen value indicates an increasing trend, while a negative value indicates a decreasing trend.

The Mann-Kendall test statistic S is calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(NDVI_j - NDVI_i)$$

where the sign function is defined as:

$$\text{sgn}(NDVI_j - NDVI_i) = \begin{cases} 1 & \text{if } NDVI_j - NDVI_i > 0 \\ 0 & \text{if } NDVI_j - NDVI_i = 0 \\ -1 & \text{if } NDVI_j - NDVI_i < 0 \end{cases}$$

The variance of S is given by:

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

1.3 Hurst Index

The Hurst index (H) was used to analyze the sustainability of NDVI trends. The rescaled range (R/S) analysis was performed:

$$R(\tau)/S(\tau) \propto (c\tau)^H$$

where c is a constant and H is the Hurst index. The interpretation is as follows: when $0.00 < H < 0.50$, the time series exhibits anti-persistence; when $H = 0.50$, the series is random; and when $H > 0.50$, the series exhibits persistence.

1.4 Coefficient of Variation

The coefficient of variation (CV_{NDVI}) was used to analyze the stability of vegetation coverage:

$$CV_{NDVI} = \frac{\sigma_{NDVI}}{\overline{NDVI}}$$

where σ_{NDVI} is the standard deviation of NDVI and $\overline{NDVI}$ is the mean NDVI value.

1.5 Partial Correlation and Residual Analysis

Partial correlation analysis was used to distinguish the effects of temperature and precipitation on NDVI. The residual analysis method was employed to quantify the impact of human activities on vegetation change. The residual ε is calculated as:

$$\varepsilon = y - y'$$

where y is the observed NDVI value and y' is the NDVI value predicted by the climate factor model.

2. Results

2.1 Temporal Variation Characteristics

From 2000 to 2018, the annual average NDVI in the Tarim River Basin showed significant interannual variation, ranging from 0.105 to 0.224, with an overall increasing trend at a rate of 4.78% per decade. The NDVI values exhibited a distinct turning point in 2008, decreasing before this year and increasing rapidly thereafter. In 2008, the NDVI value reached its lowest point, while in 2014 it reached its peak. The increasing trend after 2008 occurred at a rate of 9.42% per decade, with the trend slope being 7.12% and the correlation coefficient being 3.95%. The stability of vegetation coverage showed that the fluctuation range was 2.01%.

shows the statistical characteristics of annual NDVI variability in the Tarim River Basin.

2.2 Spatial Distribution Characteristics

The spatial distribution of vegetation coverage in the Tarim River Basin from 2000 to 2018 is shown in [Figure 3: see original paper]. The vegetation coverage exhibited significant spatial heterogeneity, with higher values in the north than in the south, and higher values in the west than in the east. Areas with relatively high vegetation coverage were primarily distributed in mountainous regions, oasis areas, and the oasis-desert interlaced zones. The vegetation distribution along the river presented a strip pattern.

The vegetation coverage change trends were categorized as: unchanged (50.80% of the area), improved (37.97%), and degraded (11.23%). The improved areas were mainly concentrated in oases with abundant water resources, including Korla, Yanqi, Aksu, Kuqa, and Kashgar, as well as the central Tianshan Mountains region. The vegetation variation near the Kuluk Tagh Mountains was relatively small.

2.3 Correlation with Climate Factors

The correlation analysis between NDVI and temperature/precipitation revealed that NDVI showed a significant negative correlation with temperature in 72.92% of the basin area, while it showed a significant positive correlation with precipitation in 82.48% of the area. The combined effects of temperature and precipitation on NDVI gradually increased from northeast to southwest, with precipitation having a more significant impact than temperature.

Partial correlation analysis further confirmed that precipitation was the dominant climatic factor influencing vegetation change in the Tarim River Basin. The areas where climate factors had positive effects on vegetation were mainly distributed in the central and western parts of the basin, while areas with negative effects were primarily located in the eastern and northern parts.

2.4 Impact of Human Activities

Residual analysis was used to distinguish the impact of human activities from climate factors. The results indicated that human activities had positive effects on vegetation change in oasis areas, oasis-desert transition zones, and the lower reaches of the Tarim River, accounting for approximately 40.02% of the basin area. Negative effects were observed in 59.98% of the area, primarily in regions with intensive agricultural development and urban expansion.

The sustainable vegetation coverage change analysis showed that 69.17% of the basin area exhibited sustainable vegetation change, mainly in oasis, oasis-desert interlaced zones, and desert areas. Unsustainable vegetation change occurred in 30.83% of the area, primarily distributed in mountainous areas and water systems.

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Note: Figure translations are in progress. See original paper for figures.