Spatiotemporal Variation of Vegetation Index and Its Influencing Factors in Yulin, Shaanxi over the Past 17 Years: Postprint

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Abstract

Vegetation indices are critical tools for studying regional vegetation dynamics. Based on MODIS/Terra NDVI remote sensing imagery, we conducted a pixel-scale analysis of spatiotemporal variations and influencing factors of August NDVI in Yulin City, Shaanxi Province from 2000 to 2016. The results indicate that 96.44% of Yulin' s area experienced increasing vegetation index, with regions exhibiting an increase rate of 0-0.02/a comprising 93.63% of Yulin' s area, and regions showing a significant increasing trend accounting for 80.72% of the total area. Multiple linear regression analysis reveals that meteorological factors exerted a promotional effect on vegetation growth and evolution, while human activities rendered the distribution of vegetation index levels more homogeneous. Areas where human activities inhibited vegetation growth and evolution accounted for 45.04% of Yulin' s total area, primarily distributed in Fugu County in the northernmost part of Yulin, as well as most southern and western regions of the city. Conversely, areas where human activities promoted vegetation index increase accounted for 54.96% of Yulin' s total area, indicating that in over half of the region, human activities facilitated vegetation growth, with measures such as mountain closure for afforestation, conversion of cropland to forest, and conversion of grazing land to grassland demonstrating effective implementation in these areas.

Full Text

Preamble

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Spatiotemporal Variation and Impact Factors of Vegetation Index in Yulin, Shaanxi Province Over the Past 17 Years

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Abstract

Vegetation index is an important method for studying regional vegetation changes. This study analyzes the spatiotemporal variations and influencing factors of NDVI in August from 2000 to 2016 at pixel scale in Yulin City, Shaanxi Province, using MODIS/Terra NDVI remote sensing data. The results show that vegetation index increased in approximately 96.44% of Yulin' s land area, with areas showing NDVI increase between 0–0.02/a accounting for 93.63% of the city' s total area. Areas with significantly increasing trends account for 80.72% of Yulin. Complex linear regression analysis reveals that meteorological factors play a positive role in vegetation growth and evolution, while human activities also make the vegetation index distribution more uniform. Areas where human activities restrain vegetation growth and evolution cover 45.04% of Yulin' s total area, mainly distributed in Fugu County in the northernmost part of Yulin and most areas in the southern and western parts of the city. Areas where human activities promote vegetation index increase account for 54.96% of Yulin' s total area, indicating that in more than half of the region, human activities have played a positive role in vegetation growth. In these areas, the effects of forest conservation, returning farmland to forests, and returning pasture to grassland are greater than in other regions.

Keywords: vegetation index; spatiotemporal change; complex linear regression; pixel scale; Yulin

Introduction

Surface vegetation represents the most active layer of the lithosphere and is the product of long-term interactions between the lithosphere, atmosphere, and hydrosphere. It plays a coordinating role in global ecosystem balance, climate change, and water cycles [1-2]. As one of the most important and sensitive components of global land cover, vegetation can reflect the impacts of climate change and human activities in a relatively short time [3]. Yulin is located at the junction of the Mu Us Desert and the Loess Plateau in northern Shaanxi, belonging to the agricultural-pastoral transition zone. The ecological environment is fragile and sensitive to change, making it a hotspot and key area for desertification research [5-6].

Previous studies on factors influencing vegetation index spatiotemporal changes have mostly been based on correlation analysis. Some scholars found that temperature plays a dominant role in affecting vegetation changes [7], while others discovered that vegetation response to precipitation and temperature shows obvious spatial differences and lag effects [8-9]. Gao et al. [10] applied correlation analysis methods to analyze grassland climate change responses. Xia Zhaohua [11] analyzed the spatiotemporal distribution patterns of NDVI across China over the past two decades and attempted to distinguish climate factors from human activity factors. Fabricante et al. [12] believed that NDVI changes correlate more strongly with total water amount from previous months. Piao et al. [13] found excellent correlation between growing season NDVI and precipitation. Li Dengke et al. [14] used simple correlation coefficient analysis to study vegetation index changes along the Great Wall in northern Shaanxi. Ding et al. [15] analyzed the seasonal and interannual variation characteristics of grassland NDVI and its correlation with precipitation and temperature in Qinghai Province. Li Lina [16] conducted correlation analysis between NDVI and precipitation at numerous points in Shaanxi Province, finding that climate impacts on vegetation differ by region and vegetation sensitivity to climate also varies. Zhu Wenbin et al. [17] found through pixel-by-pixel analysis that factors influencing vegetation cover in the Qaidam Basin mainly include precipitation, surface and groundwater conditions, elevation, and human activities. Zhao et al. [18] studied the relationship between NDVI increase and precipitation/potential evapotranspiration increases. Xu Haojie et al. [19] found that human activity is also a key factor affecting vegetation growth in local areas. Zhang Zhiyao et al. [21] discovered that temperature and precipitation are the main factors affecting vegetation growth in the Qilian Mountains. Zhang Qingyu et al. [20] studied vegetation cover changes in Inner Mongolia and found that human activity impacts on vegetation are gradually increasing.

Recent studies on Yulin and surrounding areas include: Li Dengke et al. [14] used trend line analysis methods to analyze vegetation index changes in the wind-sand area along the Great Wall in northern Shaanxi; Liu Jing et al. [24] established a remote sensing quantitative model for vegetation coverage in the Mu Us Desert; Zhou Shuqin et al. [25] applied spatial and classical statistical methods to study vegetation spatial autocorrelation patterns; Wang Jingpu et al. [26] analyzed the relationship between vegetation phenology and climate factors. However, these studies either use area-averaged analysis or unary linear regression trend methods at pixel scale. While influencing factor studies involve simple correlation or regression analysis between area-averaged NDVI and meteorological factors, or simple correlation analysis at pixel scale, no studies have conducted pixel-scale multiple regression analysis to quantitatively distinguish between meteorological and human activity impacts on vegetation index. This study combines these approaches to analyze Yulin' s vegetation index at pixel scale, enabling accurate analysis of spatiotemporal changes and meteorological factor impacts at each location, while quantitatively distinguishing between meteorological and human activity influences.

1. Study Area Overview

Yulin City is located in the northernmost part of Shaanxi Province, with geographic coordinates of 107°28 E–111°15 E, 36°57 N–39°35 N. It borders the Yellow River and Shanxi Province to the east, Ningxia Hui Autonomous Region to the west, Inner Mongolia to the north, and Yan' an City of Shaanxi to the south. The territory extends 385 km east-west and 263 km north-south, with a total land area of 43,578 km² [29-30]. In 2015, the permanent population was [Figure 1: see original paper].

The terrain of Yulin is high in the northwest and low in the southeast, with an average elevation of 1,300 m. The landform is roughly divided by the Great Wall: the north is wind-sand grassland area and the south is loess hilly-gully area. Yulin is a transition zone between eastern monsoon climate and northwest arid continental climate, as well as between the southern edge of the Mu Us Desert and the Loess Plateau of northern Shaanxi. It belongs to warm temperate semi-humid to semi-arid climate transition zone, which determines the fragility of Yulin' s ecological environment. From southeast to northwest, as distance from the sea increases, vegetation shows obvious transition and succession from temperate deciduous forest to desert.

2. Data Sources and Processing

This study uses MODIS/Terra NDVI data obtained from the MODIS/Terra website. The dataset is named "MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V005" (MOD13Q1), with a spatial resolution of 250m. MOD13Q1 files contain multiple data fields, with NDVI valid values between [range] [6].

The downloaded images were first processed using MRT (MODIS Reprojection Tool) software for batch clipping and projection. The processed images were then subjected to maximum value compositing to obtain one image per year for analysis.

2.1 Unary Linear Regression Trend Analysis

Unary linear regression trend analysis is a method that performs regression analysis on variables changing over time. It can analyze the change trend of each pixel in the study area to simulate the vegetation greenness rate of change (GRC). GRC is defined as the slope of the linear regression equation of the seasonal integrated normalized difference vegetation index (SINDVI) over a time period [31-32].

This study calculates the regression slope for each pixel to simulate its NDVI change trend and estimate the magnitude of change, using the least squares method:

[Formula for slope calculation would appear here based on the fragmented text]

Where NDVI is the NDVI value for year i; slope is the trend line slope. slope > 0 indicates increasing NDVI trend, slope < 0 indicates decreasing trend.

2.2 Correlation Analysis Test

Many phenomena in nature have certain relationships that are neither deterministic functional relationships nor completely unrelated. Correlation analysis studies the relationships between two or more random variables [33]. The correlation coefficient r   can test vegetation change trends:

[Formula for correlation coefficient would appear here]

Where n is sample number; X̄ is mean of variable x; Ȳ is mean of variable y; r is correlation coefficient between x and y.

The result is the regression coefficient between NDVI values and year for each pixel. A positive correlation coefficient indicates increasing vegetation cover, while a negative value indicates decreasing cover. If r   passes significance test at   = 0.05 level, the trend is significant.

2.3 Complex Linear Regression Analysis

This study performs complex linear regression analysis between NDVI and temperature/precipitation. The regression equation is:

z = a + bx + cy

[Formulas for parameter calculation would appear here]

Where r , r _z, r _z are correlation coefficients between x and y, x and z, y and z respectively; _z is standard deviation; z̄ is mean of z series.

The residual calculation formula is: residual = NDVI - NDVI

Where NDVI is actual observed value; NDVI is predicted value from complex linear regression model. The residual represents the contribution of human activities and other uncertain factors.

4. Results Analysis

4.1 Spatiotemporal Variation Characteristics of NDVI

Through unary linear regression trend analysis, the slope distribution map shows that most areas of Yulin appear green, indicating increasing vegetation index. The maximum slope reaches 0.044, with some areas reaching 0.0102/a. Areas with slope between 0–0.03/a account for most of the region, showing that vegetation index is increasing in most areas. Decreasing areas are sporadically distributed in western Yulin, Hengshan District, and Yuyang District, with a minimum of -0.054/a [Figure 2: see original paper].

[Table 1 shows the area and proportion of different NDVI change trends from 2000-2016]

Areas with decreasing NDVI account for only 3.37% of Yulin' s total area (1,537.44 km^2). Areas with slope between -0.01 and 0 account for 3.57%, while increasing areas account for 96.44% (41,609.76 km^2), with increases mainly between 0–0.02/a (93.63% of total area). This indicates Yulin's vegetation coverage has gradually increased in recent years.

4.2 Significance Test of Dynamic Change

Correlation analysis between NDVI images and time series yields correlation coefficients r for each pixel. After significance testing at = 0.05 level [Figure 3: see original paper]:

Areas passing the 0.05 significance test account for 99% of the study area. Significantly increasing areas account for 80.72% of total area, while significantly decreasing areas account for only 0.43%, sporadically distributed in the northwest Mu Us Desert. Areas with increasing but not significant trends account for 15.71%, sporadically distributed in Dingbian and Jingbian counties in the west. The results show a significant increasing trend in recent years.

4.3 Comparison Between 2000 and 2016

By statistically analyzing area proportions of different difference ranges between 2000 and 2016 [FIGURE:4, TABLE:2]:

Areas with increased NDVI account for 96.86% of the study area (41,793.09 km^2), with increases mainly between 0–0.4. Areas with decreased NDVI account for only 3.04% (1,311.67 km^2). The vast majority of Yulin' s vegetation index has increased, with increases mainly between 0–0.4.

4.4 Vegetation Index Level Changes

Referencing Zhou Shuqin' s research [4], Yulin' s vegetation sequence is divided into: very low coverage (NDVI 0.2), low coverage (0.2<NDVI 0.3), medium coverage (0.3<NDVI 0.4), medium-high coverage (0.4<NDVI 0.5), high coverage (0.5<NDVI 0.6), and dense coverage (NDVI>0.6). The transfer matrix from 2000 to 2016 vegetation index levels shows :

Diagonal values represent unchanged vegetation areas. The upper-right area (positive transformation) is significantly larger than the lower-left area (negative transformation), consistent with the mapping analysis results.

4.5 Quantitative Analysis of Meteorological and Human Factors

To quantitatively analyze meteorological and human activity impacts at pixel scale, meteorological data from stations within and around Yulin were spatially interpolated using the Thiessen polygon method to obtain precipitation and temperature data for each pixel. Considering the lag effect between vegetation index and temperature/precipitation, correlation analysis was performed between monthly data and NDVI. All passed t-test at = 0.05 confidence level. Therefore, this study selected August average temperature and July-August total precipitation as the meteorological sequences.

Complex linear regression analysis between 2000-2016 NDVI time series and meteorological data yields the regression equation parameters a, b, c. Using temperature and precipitation sequences, NDVI predicted values (NDVI) are obtained, and residuals (NDVI - NDVI) represent human activity contributions.

The meteorological factor contribution distribution map [Figure 5: see original paper] shows that eastern and southeastern forest-steppe areas have larger contributions, while western and northwestern wind-sand grassland areas have smaller contributions. This indicates that natural conditions in the east and southeast are more suitable for vegetation growth, while the west and northwest at the Mu Us Desert edge have harsh conditions and poor vegetation self-renewal capacity.

Under meteorological factors alone, areas with 0.3 NDVI<0.4 account for 43.32% (18,612.14 km^2), and 0.5 NDVI<0.6 account for 20.40% (8,763.92 km^2) . Comparing with actual 2016 observations shows that human activities have made vegetation index distribution more uniform. Medium vegetation coverage areas decreased by 12.22%, while dense vegetation coverage areas increased by 3.60%—the result of vegetation restoration measures like closing mountains for afforestation and returning pasture to grassland.

The human activity contribution distribution map [FIGURE:6, TABLE:5] shows that areas where human activities inhibit vegetation growth account for 45.04% of Yulin' s total area, mainly in northernmost Fugu County and western Yulin. Areas where human activities promote vegetation index increase account for 54.96%, indicating positive human impacts in over half the region.

According to 2015 Yulin Statistical Yearbook [34], areas with increased vegetation index have significantly higher forest coverage rates, primary industry added value, water conservation treatment area, and drought/flood-resistant area than areas with decreased vegetation index. These ecological projects have promoted vegetation restoration. However, implementation scale and effectiveness vary by region.

5. Conclusions

Analysis of 2000-2016 growing season vegetation index spatiotemporal variation and influencing factors in Yulin, Shaanxi using MODIS/Terra NDVI time series data yields the following conclusions:

1) Pixel-scale spatiotemporal analysis shows that 96.44% of Yulin' s area has increasing vegetation index, mainly in the 0–0.02/a range (93.63% of total area). Significantly increasing areas account for 80.72%, while significantly decreasing areas account for only 0.43%, sporadically distributed in the northwest Mu Us Desert.

2) Complex linear regression analysis shows that meteorological factors promote vegetation growth evolution, while human activities make vegetation index levels more uniform. Meteorological contributions are larger in eastern and southeastern forest-steppe areas and smaller in western and northwestern wind-sand grassland areas, indicating better natural conditions in the east/southeast and harsher conditions in the west/northwest.

3) Human activities inhibiting vegetation growth account for 45.04% of Yulin' s total area, mainly in northern Fugu County and western Yulin. Human activities promoting vegetation index increase account for 54.96%, indicating positive roles in over half the region. In these areas, forest conservation, returning farmland to forests, and returning pasture to grassland measures have been effective.

4) Under relatively stable current human activity conditions, future vegetation conditions can be theoretically predicted based on temperature and precipitation, providing reference for regional ecological restoration and environmental protection.

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