Spatiotemporal Characteristics and Driving Factors of Vegetation Cover in the Guanzhong Plain Urban Agglomeration: Postprint

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Abstract

Vegetation serves as a crucial indicator of environmental changes in global and regional ecosystems and constitutes a significant resource contributing to human societal activities. To investigate the response of vegetation cover changes to natural and anthropogenic factors across different regions of the Guanzhong Plain urban agglomeration, this study employs vegetation divided into three regions as the research object, utilizing MODIS-NDVI remote sensing data from 2000 to 2017. Through trend analysis, exploratory spatial data analysis, and the Geographical Detector method, the evolution and distribution characteristics of vegetation cover during the 18-year period are examined from both temporal and spatial perspectives, with quantitative analysis of the dominant influencing factors. Remote sensing data were processed via projection transformation, mosaicking, and maximum value composition, followed by batch image cropping using Python programs. Zonal statistics were performed on both remote sensing and meteorological data, after which the processed data were analyzed and discussed. The results indicate: (1) During the study period, vegetation cover in the Guanzhong Plain urban agglomeration exhibited a significant increasing trend, with a mean NDVI growth rate of $0.077 \cdot (10\ \mathrm{a})^{-1}$. Phased change characteristics were pronounced, with extremely significant increases during the 2005–2007 and 2011–2013 periods, reaching a maximum increase rate of $0.05 \cdot \mathrm{a}^{-1}$. (2) Spatially, an overall distribution pattern of "higher in the south and lower in the north" was observed, with the study area showing overall improvement. High-value areas were primarily distributed on the northern slopes of the Qinling Mountains in the south, more strongly influenced by climatic factors, with vegetation cover increasing slowly to achieve slight improvement levels. Low-value areas clustered in the marginal regions of the Loess Plateau, showing marked increasing trends. In very few areas of the central Guanzhong Plain, vegetation cover experienced slight or severe degradation, most notably in Xi' an City and adjacent urban areas. (3) Hotspot areas were mainly distributed in the Qinling mountainous region and the central Guanzhong Plain, while coldspot areas concentrated in the marginal regions of the Loess Plateau, with vegetation cover demonstrating overall growth. The number of grid cells in hotspot areas continued to increase, peaking at 45.07% in 2013. The number of coldspot areas continuously decreased, dropping to 9.82% in 2017. Sub-hotspot and sub-coldspot areas were primarily distributed across the central plain and northern regions, transitioning from contiguous to scattered distribution with continuously decreasing total amounts. (4) Natural factors exerted the most prominent influence on vegetation cover, with temperature and precipitation being the dominant factors, exhibiting determinant power q values of 0.955 and 0.931, respectively, and temperature demonstrating greater influence than precipitation. Anthropogenic factors also showed significant influence, with the GDP factor achieving a determinant power q value of 0.387. This study can provide a theoretical basis for local improvements to the vegetation cover environment.

Full Text

Spatio-temporal Characteristics and Influencing Factors of Vegetation Coverage in the Guanzhong Plain Urban Agglomeration

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Abstract

Vegetation serves as a crucial indicator of environmental changes in global and regional ecosystems and constitutes one of the resources that make significant contributions to human social activities. To investigate how vegetation coverage changes respond to natural and anthropogenic factors across different regions of the Guanzhong Plain urban agglomeration, we divided the study area into three vegetation zones and selected MODIS-NDVI remote sensing data from 2000 to 2017. Using trend analysis, exploratory spatial data analysis, and geodetector methods, we examined the evolution and distribution characteristics of vegetation coverage from both temporal and spatial perspectives, and quantitatively analyzed the dominant factors influencing vegetation coverage. Remote sensing data were processed through projection conversion, mosaicking, and maximum value compositing, followed by batch image cropping using Python programs. Both remote sensing and meteorological data were subjected to zonal statistics, after which the processed data were analyzed and discussed. The results indicate: (1) During the study period, vegetation coverage in the Guanzhong Plain urban agglomeration showed a significant upward trend, with the NDVI average growth rate reaching 0.077 per decade. The characteristics of periodic changes were evident, with extremely significant increases during the 2005–2007 and 2013–2015 stages, reaching a maximum ascending rate of 0.05 per year. (2) Spatially, the distribution exhibited an overall pattern of "high in the south and low in the north," with the entire study area showing overall improvement. High-value areas were mainly distributed on the northern slopes of the southern Qinling Mountains, where climate factors exerted greater influence, vegetation coverage increased slowly, and reached a level of slight improvement. Low-value areas clustered along the margins of the Loess Plateau, where vegetation showed obvious increasing trends. Only a very small portion of the central Guanzhong Plain experienced slight or severe vegetation degradation, with Xi' an and adjacent cities being the most typical examples. (3) Hotspot areas were primarily distributed in the Qinling Mountains and the central Guanzhong Plain, while cold spots concentrated along the Loess Plateau margins, where vegetation coverage was predominantly increasing. The number of hotspot grid cells continued to increase, reaching a maximum of 45.07% in 2013, while cold spot areas continuously decreased to 9.82% in 2017. Sub-hotspot and sub-cold spot areas, mainly distributed in the central plain and northern regions, transformed from contiguous to scattered distributions with continuously decreasing total amounts. (4) Natural factors had the most prominent influence on vegetation coverage, with temperature and precipitation being the dominant factors, showing determinant q-values of 45.07% and 9.82% respectively, and temperature exerted greater influence than precipitation. The influence of anthropogenic factors was significant but less pronounced, with the GDP factor' s determinant q-value reaching 38.7%. This study can provide a theoretical basis for improving the vegetation coverage environment in the region.

Keywords: NDVI; trend analysis; ESDA; Geodetector; Guanzhong Plain urban agglomeration

1. Introduction

Vegetation is an indispensable component of terrestrial ecosystems, playing a significant role in environmental protection and soil and water conservation, and even profoundly affecting global climate change and energy circulation systems. Consequently, interannual climate change and dynamic monitoring of vegetation coverage have become research priorities both domestically and internationally. With the continuous development of remote sensing technology, the extraction of vegetation data has been enhanced. The MODIS series products are widely used in research on climate change and vegetation coverage, providing important scientific basis and practical value for monitoring vegetation dynamics. The Normalized Difference Vegetation Index (NDVI), as a quantitative representation of vegetation coverage, can directly reflect vegetation coverage and its evolution process, and holds great research value for numerous ecological change processes and development states, including biomass.

In recent years, breaking the constraints of natural environments on economic development and achieving global sustainable development have gradually become research hotspots, making the spatio-temporal evolution of vegetation coverage even more significant. Domestic and international scholars investigating vegetation coverage changes have primarily relied on remote sensing satellite inversion data. Research has made substantial contributions to global vegetation coverage studies, mainly covering two aspects: natural factors and anthropogenic factors. Studies have found that vegetation in Central Asian regions is particularly sensitive to climate change, with annual NDVI values positively correlated with annual precipitation and weakly negatively correlated with temperature changes. In China' s mid- to high-latitude regions, NDVI values show a declining trend. Within a certain range, NDVI values gradually decrease with increasing elevation. Vegetation on the Tibetan Plateau exhibits a stepped spatial distribution pattern with significant seasonal spatial differences. In the Altay region, vegetation coverage changes are negatively correlated with temperature in most areas, with some regions showing decreased coverage due to warming temperatures.

Although vegetation coverage changes are primarily influenced by natural factors, the impact of human activities cannot be ignored. Research in Inner Mongolia' s ecological zones has found that while NDVI changes are greatly affected by natural factors, human activities also exert strong promoting or inhibiting effects on vegetation within the ecological zone. Particularly in North China' s vegetation improvement and degradation areas, human activities have greater influence than climate change. Based on stability assessments, future trends have been predicted.

Comprehensive review of previous vegetation coverage research reveals that study areas have mainly concentrated in regions with relatively good natural conditions, with insufficient research on arid areas in central and western China. Moreover, some studies have only quantitatively analyzed influencing factors of vegetation coverage, and few scholars have conducted comprehensive studies on vegetation coverage changes and influencing factors in regions with complex and diverse natural conditions, especially ecologically sensitive areas like the Guanzhong Plain urban agglomeration. Situated between the Qinling Mountains and the Loess Plateau, this region exhibits complex natural zoning characteristics, and research on its geographical elements remains relatively weak. Analyzing the spatio-temporal variation characteristics and key influencing factors of vegetation coverage in this region can help better understand the dynamic change patterns of vegetation coverage, grasp the direction of ecosystem evolution, and reveal the interactions within the human-land regional system. Therefore, this paper utilizes NDVI data from 2000 to 2017 to study the spatio-temporal evolution of vegetation coverage in the Guanzhong Plain urban agglomeration, analyze its temporal evolution characteristics and spatial distribution patterns, and quantitatively identify the dominant factors affecting vegetation coverage, aiming to provide a scientific basis for rationally responding to regional ecological environmental changes and making adjustments.

2. Study Area Overview

The Guanzhong Plain urban agglomeration includes 11 prefecture-level administrative units in Shaanxi Province, 2 county-level administrative units in Gansu Province, and 2 in Shanxi Province. It extends from Wushan County in Tianshui City in the west to Fushan County in Linfen City in the east, spanning 10.71 longitudinal degrees. It borders the Qinling Mountains in the south and reaches Linfen in the north, covering an area of 3.748×10^{4} km^2 with significant terrain undulation. The topography can be divided into three parts: the northern Loess Plateau marginal area, the central Guanzhong Plain area, and the southern Qinling Mountain area. The region is situated between the Qinling Mountains and the Loess Plateau, serving as a critical zone in China. The climate is warm and humid, with an average annual temperature of 800 mm and large north-south differences. The central and eastern regions have lower average elevations, dominated by plains that constitute the main distribution areas for settlements and farmland. The northern slopes of the Qinling Mountains feature temperate and mid-temperate climate environments, with main vegetation types including broadleaf forests, coniferous forests, mixed coniferous-broadleaf forests, and alpine meadows, providing favorable conditions for vegetation growth and coverage.

[Figure 1: see original paper]

3. Data and Methods

3.1 Data Sources and Processing

We used MOD13 NDVI product data with a temporal resolution of 16 days, sourced from NASA (https://modis.gsfc.nasa.gov), with a spatial resolution of 500 m and remote sensing satellite orbit numbers h26v05 and h27v05. Through projection conversion, mosaicking, and maximum value compositing methods, we processed the NDVI data to a monthly temporal resolution for analysis. We then applied Python programs for batch image cropping to obtain the study area' s NDVI dataset. Using ArcGIS, we extracted monthly maximum and average values as basic data for spatial analysis, assigning NDVI values to 5 km$\times$5 km grids and removing outliers. We defined the period from April to October as the vegetation growing season and used the average NDVI during the growing season to represent annual vegetation coverage status.

Meteorological data were obtained from the China Meteorological Data Sharing Network. Due to data availability limitations, we selected monthly average temperature and precipitation data from 2000 to 2017 at effective stations within the study area. We performed spatial interpolation on monthly temperature and precipitation data to obtain spatial datasets. Based on climate impact factors, we incorporated GDP data and used geodetector methods to analyze the dominant influencing factors and their degrees of influence on vegetation coverage from 2000 to 2017.

3.2 Research Methods

3.2.1 Spatio-temporal Hotspot Analysis Hotspot analysis has received widespread attention in ecology, regional economics, soil science, and related fields, offering significant advantages in studying spatial location relationships and being crucial for analyzing the correlation degree of individual spatial units within a region. Vegetation coverage in the Guanzhong Plain urban agglomeration shows obvious spatial agglomeration characteristics, particularly with substantial north-south differences greatly influenced by terrain and climate, making analysis of local agglomeration patterns particularly important. Specific calculation methods are detailed in reference [28].

3.2.2 Trend Analysis The slope of the regression equation (slope) represents the slope of NDVI during the monitoring period in the study area, reflecting vegetation change trends and characteristics. We conducted trend analysis on the spatial distribution characteristics of vegetation coverage changes in different periods to deduce spatial variation patterns of vegetation coverage. The calculation formula is as follows:

$$slope = i \times NDVI_i - \sum NDVI_i \quad i = 1$$

where: n is the length of the study time series; i represents the ith year; NDVI_i denotes the NDVI value in year i; and slope represents the trend line slope. If slope > 0, it indicates an increasing trend in vegetation coverage area within that grid cell, with larger values indicating stronger trends and better vegetation improvement. Conversely, a decreasing trend is indicated.

3.2.3 Geodetector Geodetector is primarily designed for categorical data. To analyze the dominant factors of NDVI changes in the Guanzhong Plain urban agglomeration, we selected temperature, precipitation, population, and GDP as factors for analysis using the geodetector method, calculating their impacts on vegetation coverage. By comparing the q-values of each factor, we quantitatively analyzed the dominant factors of vegetation coverage. The model is as follows [33]:

$$L \frac{N_h \sigma^2}{N \sigma^2} \sum h - 1$$

where: the q-value represents the determining power of influencing factor (X_i) on the spatial distribution of vegetation changes, with a value range of [0,1]. A larger q-value indicates greater influence of the factor (X_i) on vegetation coverage, and vice versa. When the value is 0, it indicates that factor (X_i) has no relationship with vegetation coverage (Y), showing random vegetation distribution. N and σ^2 represent the explanatory variable and variance of vegetation coverage in the study area, respectively; σ^2_h is the variance of a certain variable; and L represents the number of strata, i.e., the classification layers of influencing factors.

4. Results and Analysis

4.1 Spatio-temporal Pattern Characteristics

4.1.1 Temporal Variation Characteristics From 2000 to 2017, NDVI in the Guanzhong Plain urban agglomeration showed a slow upward trend, with average growing-season NDVI values all greater than 0.6, indicating good baseline vegetation coverage conditions. The average NDVI value in 2017 reached 0.73, while the minimum appeared in 2000 at 0.59, with the maximum occurring in 2015 at 0.76, showing overall fluctuating growth in NDVI. The interannual variation average can be divided into four ascending periods in the temporal dimension: the first ascending period (2000–2003), second ascending period (2005–2007), third ascending period (2010–2013), and fourth ascending period (2015–2017). Among these, the second and third ascending periods showed significant increases, with growth acceleration also increasing slightly. Five descending periods occurred: the first (2003–2005), second (2007–2008), third (2013–2014), fourth (2014–2015), and fifth (2017). The interannual NDVI average showed a slow upward change with a rate of 0.077 per decade, accelerating after 2013 (Figure 2).

[Figure 2: see original paper]

4.1.2 Spatial Differentiation Characteristics Spatially, vegetation coverage in the Guanzhong Plain urban agglomeration exhibited an overall pattern of "high in the south and low in the north," with fragmentation in plain areas. To clearly identify vegetation coverage evolution, we selected data from inflection point years for visualization (Figure 3), considering maximum vegetation growth differences. Due to the complex and diverse natural conditions in the study area, we specifically divided it into three regions: the northern Loess Plateau marginal area, the central Guanzhong Plain area, and the southern Qinling Mountain area.

The Qinling Mountain area naturally contains large amounts of vegetation, belonging to temperate monsoon and semi-humid zones that provide favorable hydrothermal conditions for plant growth, with relatively high vegetation coverage. This includes parts of Tianshui City, Baoji City, Shangluo City, and Yuncheng City. In addition to natural ecological restoration, protection measures such as enclosure for conservation, returning farmland to forest and grassland, and afforestation have been implemented to improve vegetation coverage and ecological environment. The central Guanzhong Plain area has medium-level vegetation coverage conditions, significantly influenced by human activities. This region is dominated by artificial vegetation, with cultivated land comprising various crops, vegetables, orchards, and urban green spaces. Affected by urban expansion, overall vegetation coverage area is relatively small, with severe degradation around cities. Some low-value areas are gradually being replaced by high-value areas, which developed from scattered distribution to patchy distribution, indicating improved vegetation coverage.

The northern Loess Plateau marginal area is primarily influenced by geographical conditions and climate factors, with precipitation being the most direct influencing factor. Due to the extreme sensitivity of the Loess Plateau, severe soil erosion, and extreme water shortage, vegetation is greatly reduced, severely restricting large-scale vegetation coverage and resulting in low coverage across most areas. With environmental governance efforts, areas east of Tongchuan City have gradually developed into high-value areas, with vegetation coverage gradually improving.

[Figure 3: see original paper]

4.2 Dynamic Evolution Characteristics

4.2.1 Trend Variation Characteristics Trend analysis effectively reflects the evolution direction of NDVI in the Guanzhong Plain urban agglomeration during the study period, showing increasingly obvious trends from south to north, with degradation occurring only in very small central areas (Figure 4). Vegetation degradation concentrated in regions with rapid urbanization such as Xi' an and Baoji. Specifically, vegetation coverage in the northern part of the study area improved significantly, especially in Tianshui City, Pingliang City, and Xifeng District in Gansu Province along the Loess Plateau margins. These areas are key implementation regions for the national Grain for Green program. Through transforming environmental protection concepts such as afforestation and returning farmland to forest, significant water conservation and soil retention effects have been achieved, continuously improving ecological conditions and the spatial foundation for vegetation growth.

Slight improvement areas were contiguously distributed in the southeastern Qinling Mountain area. With suitable climate conditions for vegetation growth and good baseline vegetation coverage, positive human impacts, policy protection, and enhanced environmental awareness have led to steadily increasing vegetation coverage at a relatively slow growth rate. Severe degradation areas concentrated in central Xi' an, where the region is dominated by farmland. To support rapid urbanization, large surrounding areas have been occupied, including conversion of cultivated land, grassland, and forest land to construction land and public land, thereby reducing vegetation coverage area in economically developed regions and their surroundings, with NDVI values decreasing significantly. Urban expansion caused obvious NDVI declines in surrounding areas, but its indirect impacts on vegetation destruction are even more concerning, with severe degradation occurring in areas such as Jintai District, Yangling Agricultural High-tech Industry Demonstration Zone, Xincheng District, Lianhu District, and Beilin District. Slight degradation areas were scattered around severely degraded regions and in some areas with better economic foundations, such as

Fengxiang County, Fufeng County, and Wugong County.

[Figure 4: see original paper]

4.2.2 Spatial Agglomeration Characteristics We employed optimized hotspot analysis to further examine spatial pattern evolution characteristics of vegetation coverage, identifying spatial clusters of statistically significant high values (hotspots) and low values (coldspots) to achieve deeper understanding. Using 5 km$×$5 km grid cells as objects, Z-values after visualization were classified by natural breaks into four categories: coldspots, sub-coldspots, sub-hotspots, and hotspots, generating spatial pattern evolution maps of vegetation coverage hotspots and coldspots in the Guanzhong Plain urban agglomeration.

Hotspot areas showed obvious agglomeration patterns on the northern slopes of the Qinling Mountains, northwestern Baoji City, northeastern Xianyang City, and southeastern Yuncheng City (Figure 5). Due to favorable natural environments, large areas of vegetation coverage have formed. In 2000, there were 1,247 hotspot grids, showing a clear numerical increase. Spatially, high-value areas have expanded to include northern Baoji City, northern Weinan City, and most central areas of the Guanzhong Plain, gradually developing eastward along the plain margins to Xia County, Jiang County, and Fushan County, with coverage increasing from 31.28% to 40.43%. Connections between regional vegetation coverage have continuously strengthened, with spatial heterogeneity weakening.

Coldspot areas are distributed along the Loess Plateau margins and most parts of northern Weinan City, Yuncheng City, and Linfen City in the study area. However, under natural recovery and human regulation, coldspot areas have continuously decreased, with grid numbers reduced from 21.41% to 11.41% by 2017. Sub-hotspot and sub-coldspot areas were contiguously distributed in the central plain, Loess Plateau gully regions, and Fenwei Plain areas, affected by both natural and human factors. These areas have also transformed from patchy to scattered distribution, embedded between hotspot and coldspot areas, with grid numbers decreasing from 13.40% to 3.40%. Coldspot areas in the central and eastern regions have decreased significantly. The central Guanzhong Plain area has experienced strong human disturbance under negative impacts, with economic development and urban expansion forcing reductions in vegetation coverage in suburban areas, causing coldspot areas around cities like Xi' an and Xianyang to gradually expand. In the Loess Plateau marginal areas, under policy guidance, some regions have transformed from coldspots to sub-coldspots, with vegetation coverage development trends improving.

[Figure 5: see original paper]

4.3 Influencing Factor Analysis

Vegetation coverage in the study area is comprehensively affected by natural, human, and social factors. This paper uses NDVI values as vegetation coverage indicators, with multi-year average temperature (tem) and multi-year average precipitation (pre) as influencing factor indicators, applying geodetector analysis to examine impacts of anthropogenic and natural factors on vegetation coverage changes. Factor detection primarily compares spatial differentiation of influencing factors through q-values. We selected factor detection results for analysis, showing the descending order of determinant power as: temperature (0.955) > precipitation (0.931), with $p < 0.05$, indicating statistical significance. Temperature, precipitation, and GDP all have different degrees of impact on the spatial differentiation of vegetation coverage and are all main influencing factors.

The q-values of all detection factors showed high values, indicating that each factor had relatively large influence on vegetation coverage (Table 1). From the spatial differentiation results, temperature had the most significant impact on vegetation and was the dominant factor affecting vegetation coverage changes. It not only directly affects vegetation growth processes but also significantly influences plant species, manifested in the different spatial distributions of large amounts of coniferous forests, broadleaf forests, and shrublands in mountainous areas. The temperature factor' s q-value reached 0.955, indicating greater influence of temperature on vegetation growth in this region, while the precipitation factor' s q-value was 0.931, also showing relatively high influence. This demonstrates that natural factors are the primary controlling factors in vegetation growth processes. Overall, climate is the dominant driving factor for vegetation coverage. The Taibai Mountain area remains lush and green year-round, mainly because during summer it is affected by warm and moist airflows from the southwest and Pacific Ocean, creating hot and humid conditions. North of the Qinling Mountains lies a temperate monsoon, semi-humid zone that is also very conducive to plant growth, with main vegetation types including coniferous forests, broadleaf forests, mixed forests, alpine shrublands, and alpine meadows, resulting in relatively high NDVI values in this region.

GDP serves as a secondary controlling factor. Although urban surrounding areas are also affected by urbanization, development has just begun and is still in its initial stage, so it has not yet reached a high level of influence on ecological aspects. Although the q-value is slightly smaller than that of climate factors, it still has strong influence. Anthropogenic factors include both promoting and inhibiting effects: on one hand, to cope with rapid urban expansion and high-speed economic development, humans have had to occupy suburban and surrounding areas of cultivated land, grassland, and forest land, reducing vegetation coverage area. On the other hand, vegetation protection policies have been proposed, vigorously advocating for the Grain for Green program. Particularly through the implementation of the Three-North Shelter Forest Program, combining biological and engineering measures with comprehensive management of mountain systems and sub-watersheds, large areas of water conservation forests have been created, effectively improving ecological environmental quality.

5. Conclusions

This study analyzed MODIS-NDVI time-series images of the Guanzhong Plain urban agglomeration using ArcGIS 10.2 software. Through hotspot analysis, trend analysis, and geodetector methods, we examined the temporal evolution and spatial distribution of vegetation coverage, quantitatively analyzing dominant and other influencing factors. The results show:

1) From 2000 to 2017, vegetation coverage during the growing season in the Guanzhong Plain urban agglomeration showed a fluctuating upward trend, with an average increase rate of 0.077 per decade. The 2005–2007 and 2013–2015 stages showed particularly significant increases. Growing-season NDVI average values all exceeded 0.6, with a maximum value of 0.76, indicating good vegetation coverage levels.

2) Vegetation coverage varied significantly across regions with different development rates, but overall showed improvement. The Loess Plateau marginal areas, most affected by precipitation, showed continuous vegetation increase and significant improvement under policy protection. Most areas of the Guanzhong Plain showed obvious improvement trends, with only Xi' an and surrounding areas experiencing severe or slight degradation due to human activities outweighing climate factors. Southern Qinling Mountain vegetation, more influenced by climate factors, remained basically unchanged.

3) The number of hotspots continuously increased from 31.75% to 45.15%, mainly concentrated on the northern slopes of the Qinling Mountains and central Guanzhong Plain, slowly expanding eastward. Coldspot numbers continuously decreased from 21.41% to 11.41%, gradually shifting from the north to the northwestern Loess Plateau gully region. Sub-hotspot and sub-coldspot areas transformed from contiguous distribution in plain areas to scattered distribution, with continuously decreasing total amounts.

4) Climate factors had more prominent influence on vegetation coverage as the dominant factor, with precipitation and temperature showing determinant q-values of 0.931 and 0.955 respectively, significantly affecting vegetation coverage, and temperature exerting greater influence than precipitation. GDP' s determinant power on regional vegetation coverage was 0.387, indicating relatively minor influence.

6. Discussion

Through local spatial autocorrelation analysis, this paper explored vegetation change trends within the study area, finding that different regions have different dominant factors affecting vegetation. Due to significant topographic variation across the Loess Plateau marginal areas, Guanzhong Plain, and Qinling Mountains, spatial heterogeneity is pronounced, with diverse vegetation types and considerable differences in vegetation coverage and change trends among different regions. For specific vegetation restoration and construction work, the Loess Plateau region, Guanzhong Plain region, and Qinling Mountain region should be studied separately, with targeted research on dominant factors for different vegetation types in each region. Classified research on the resource endowments of the study area is necessary to prescribe the right remedies and maximize vegetation improvement effects.

Vegetation in the Loess Plateau region primarily depends on precipitation for growth, showing strong dependence on precipitation factors. However, this region suffers severe water shortage and poor soil water retention, resulting in low vegetation coverage. Therefore, construction priorities should focus on artificial water conservation and soil fixation techniques for vegetation restoration. In plain areas, besides natural conditions, anthropogenic factors cannot be ignored. Policy measures should be strengthened for vegetation management, including enclosure protection and prohibiting grazing on returned farmland. The Qinling Mountains have natural conditions highly suitable for vegetation growth, with weak negative human impacts, requiring strict control of resource development.

The meteorological data used in this paper were obtained through interpolation analysis, which greatly affected accuracy. Future research should reconsider data source acquisition for precise classification of different region types to enhance research value. This study covers a relatively large area at the urban agglomeration level, lacking consideration of intra-city vegetation impacts and not reflecting each city' s evolution path and trends. Research should be conducted by city according to actual resources to provide specific references for intra-city vegetation coverage.

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