Spatiotemporal Variation of Vegetation Cover and Its Driving Factors in Shaanxi Province in the Context of Ecological Construction: Post-print

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Abstract

To reverse the trend of ecological degradation in recent years, China has implemented a series of national-level ecological restoration projects, with vegetation restoration as their core objective. Based on MODIS NDVI data products, meteorological station observation data, and statistical yearbooks, this study analyzed the spatiotemporal variation of vegetation cover in Shaanxi Province from 2002 to 2016 and conducted an attribution analysis using a panel data fixed-effects model. The results indicate that: (1) Following the implementation of the Grain-for-Green Program and Natural Forest Protection Program, the overall vegetation cover in Shaanxi Province exhibited an improving trend, albeit with pronounced temporal fluctuations and spatial heterogeneity. (2) Ecological restoration projects exerted a significant positive effect on vegetation recovery in Shaanxi Province, with a noticeable time-lag effect; a 1 percentage point increase in the afforestation rate resulted in an average NDVI increase of 0.012 3($p < 0.01$) in counties three years later, equivalent to the effect of a 56 mm increase in annual precipitation. (3) Increases in precipitation and temperature had significant positive effects on vegetation restoration in Shaanxi Province, whereas population and economic growth had significant negative effects. Therefore, Shaanxi Province should continue to increase investment in ecological restoration projects and strengthen supervision and monitoring evaluation; actively promote ecological migration policies to alleviate ecological pressure from human activities; adjust its economic structure and transform its economic growth mode, abandoning the resource-intensive and environmentally damaging extensive development model.

Full Text

Abstract

Since the end of the 20th century, China has implemented a series of national ecological construction programs to reverse the trend of ecological degradation, with vegetation restoration as the core objective. This study examines the effectiveness of these programs in Shaanxi Province and clarifies the roles of various driving factors. Based on MODIS NDVI data products, meteorological station observations, and socioeconomic statistics, we analyzed spatiotemporal vegetation cover changes in Shaanxi from 2002 to 2016 and built a panel-data fixed-effect model for attribution. The results show: (1) Following the implementation of the Grain for Green Program and Natural Forest Conservation Program, vegetation cover in Shaanxi showed an overall improving trend, but with significant temporal fluctuations and spatial heterogeneities. (2) Ecological construction projects exerted a significant positive effect on vegetation restoration with a time lag. The NDVI value for each county is expected to increase by 0.0123 after a 1% increase in afforestation rates three years prior, equivalent to the effect of increasing annual precipitation by 56 mm. (3) Increases in precipitation and temperature had significant positive effects on vegetation restoration. NDVI values for each county are expected to increase by 0.0216 and 0.0439 after a 100 mm increase in precipitation and a 1°C increase in temperature, respectively. However, population and economic growth exerted significant negative impacts. The NDVI value for each county is expected to decrease by 0.0331 and 0.0315 after a 1-unit increase in population density and intensity of economic activity, respectively.

Keywords: ecological construction; vegetation cover; NDVI; fixed effect model; Shaanxi Province

1 Introduction

Shaanxi Province is located in the heart of China' s Loess Plateau, where ecological degradation has been severe. Since 1999, the province has implemented large-scale ecological restoration programs including the Grain for Green Program and Natural Forest Conservation Program. Monitoring and evaluating the effectiveness of these programs is crucial for sustainable ecosystem management. Previous studies have analyzed vegetation cover changes and their relationship with environmental factors using NOAA time series data [1-2], and investigated the impact of ecological construction on vegetation change in northern Shaanxi [7-9]. However, comprehensive assessment of program effectiveness while controlling for multiple driving factors remains limited. This study employs MODIS NDVI data from 2002-2016 to quantify vegetation restoration outcomes and uses a panel data approach to isolate the effects of ecological construction from climatic and socioeconomic factors.

2 Data and Methods

2.1 Study Area and Data Sources

The study area covers Shaanxi Province, comprising three distinct physiographic regions: the Loess Plateau, Guanzhong Plain, and Qinba Mountains. The dataset includes: (1) MODIS NDVI products (2002-2016) with spatial resolution of 250m and temporal resolution of 16 days; (2) meteorological observations from 97 national weather stations covering 82% of the province; and (3) county-level socioeconomic statistics including afforestation rates, population density, and GDP.

2.2 Analytical Methods

We calculated annual maximum NDVI values and performed linear trend analysis. A fixed-effects panel data model was constructed to quantify relationships between NDVI and driving factors:

$$NDVI_{it} = \alpha_i + \beta_1 Afforestation_{i,t-3} + \beta_2 Precipitation_{it} + \beta_3 Temperature_{it} + \beta_4 Population_{it} + \beta_5 Economic_{it} +$$

where α_i represents county-specific fixed effects capturing time-invariant factors such as topography and soil conditions. The three-year lag for afforestation accounts for vegetation establishment time.

3 Results

3.1 Temporal Trends of NDVI

From 2002 to 2016, NDVI in Shaanxi showed a significant increasing trend ($p < 0.01$). The improvement accelerated after 2011, with the mean NDVI increasing from 0.6649 in 2002 to 0.78 in 2016. During 2002-2010, the trend was relatively stable, while during 2011-2016, NDVI increased at a rate of 0.0123 per year ($p < 0.01$) [Figure 2: see original paper].

3.2 Spatial Distribution of NDVI

Approximately 54.95% of Shaanxi' s area exhibited NDVI improvement, with 39.85% showing significant increase ($p < 0.05$). The spatial pattern revealed: (1) In 2002, areas with NDVI of 0.00-0.20, 0.20-0.40, 0.40-0.60, and 0.60-1.00 accounted for 1.33%, 11.28%, 23.83%, and 63.56% of the province, respectively; (2) By 2010, the distribution shifted to 0.27%, 6.38%, 22.23%, and 71.12%; (3) By 2016, high-NDVI areas (>0.60) reached 78.55% [Figure 3: see original paper]. The Loess Plateau region showed the most dramatic improvement, with NDVI increasing by 0.1852 in some counties.

3.3 Driving Factors Analysis

The Hausman test ($p < 0.05$) confirmed the appropriateness of the fixed-effects model. Results show:

1. **Ecological construction**: A 1% increase in afforestation rate three years prior increased NDVI by 0.0123 ($p < 0.01$), equivalent to the effect of 56 mm additional precipitation.
2. **Climate factors**: A 100 mm precipitation increase raised NDVI by 0.0216 ($p < 0.01$); a 1°C temperature increase raised NDVI by 0.0439 ($p < 0.01$).
3. **Human activities**: A 1-unit increase in population density decreased NDVI by 0.0331 ($p < 0.01$); a 1-unit increase in economic activity intensity decreased NDVI by 0.0315 ($p < 0.01$).

Time-lag analysis revealed that precipitation effects manifest within one year, while afforestation effects peak at 3-5 years [Figure 4: see original paper].

4 Discussion

4.1 Effectiveness of Ecological Construction Programs

The significant positive coefficient for lagged afforestation confirms that ecological construction programs have been effective in Shaanxi. The three-year lag aligns with typical vegetation establishment periods for trees and shrubs planted under the Grain for Green Program. The effect magnitude (0.0123 NDVI increase per 1% afforestation) demonstrates substantial restoration success, particularly in the Loess Plateau where afforestation rates exceeded 30% in some counties.

4.2 Relative Importance of Driving Factors

Precipitation emerged as a primary natural driver, with each 100 mm increase producing nearly double the effect of a 1% afforestation increase. However, temperature effects were even stronger (0.0439 per °C), likely reflecting improved growing conditions in this temperate region. The negative impacts of population density (-0.0331) and economic intensity (-0.0315) underscore the ongoing conflict between development and conservation. From 2002 to 2016, Shaanxi' s population grew from 36.7 to 38.1 million while GDP (in constant 2002 CPI) expanded from 2.25×10^{11} to 1.32×10^{12} RMB, exerting considerable pressure on ecosystems.

4.3 Policy Implications

To consolidate restoration achievements: (1) Continue increasing investment in ecological construction programs while strengthening supervision and monitoring; (2) Implement ecological migration policies to relieve human pressure in fragile areas; (3) Adjust economic structure and transform growth patterns

away from resource-intensive development; (4) Account for time-invariant factors like topography when designing local adaptation measures. The fixed-effects model reveals that unobserved factors such as geomorphology significantly influence vegetation baseline conditions, requiring tailored approaches for different regions.

References

[1] MA Hongyu, WANG Changyao, NIU Zheng, et al. Analysis of the vegetation cover change and the relationship between NDVI and environmental factors by using NOAA time series data[J]. Journal of Remote Sensing, 1998, 2(3): 204-210.

[2] ZHANG Xiaoye, CHEN Jun, ZHAO Yao. Impact of China' s grain for green project on the ecological environment in northern Shaanxi Province[J]. Beijing Agriculture, 2011, (27): 48-51.

[5] LIU Yu, FU Bojie. Topographical variation of vegetation cover evolution and the impact of land use/cover change in the Loess Plateau[J]. Arid Land Geography, 2013, 36(6): 1097-1102.

[6] LI Wangjun, LV Changhe. Effects of ecological building on the vegetation change in northern Shaanxi Province[J]. Arid Land Geography, 2014, 37(2): 318-324.

[7] LIU Minxia, ZHAO Ruidong, SHAO Peng, et al. Temporal and spatial variation of vegetation coverage and its driving forces in the Loess Plateau from 2001 to 2015[J]. Arid Land Geography, 2018, 41(1): 99-108.

[8] LI Jun, WANG Xuechun, SHAO Ming' an, et al. Change of NDVI based on NOAA image in northwest arid area of China in 1981-2001[J]. Arid Land Geography, 2008, 31(6): 940-945.

[9] WEI Zhenfeng, WANG Deguang, ZHANG Chong, et al. Response of vegetation cover to climate change and human activities in northwest China during 1999-2010[J]. Journal of Desert Research, 2014, 34(6): 1665-1670.

[10] GAO Jixi, YANG Zhaoping. Restoration of ecological functions: Goal and orientation of ecological restoration in China[J]. Journal of Ecology, 2015, 31(1): 1-6.

[18] CHEN Zhenglin, GE Dun. Review on the construction of grain to green project[J]. Modern Agricultural Science and Technology, 2011, (22): 240-243.

[21] SHAO Liquan, CHEN Haibin, ZHANG Chen, et al. Effects of major ecological policies[J]. China Soft Science, 2006, (6): 53-59.

[23-24] (Citation references for study area description)

[25] (Reference for afforestation lag analysis)

[26] (Reference for climate factor analysis)

[32] (Reference for economic impact analysis)

[33] (Reference for policy effectiveness)

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