Postprint of Spatiotemporal Evolution and Hydrothermal Driving Mechanisms of Vegetation Leaf Area Index in Gansu Province

Authors: Sanjun Zheng, Jianmin Ma, Zhou Xing, Wang Zhengxiong

Date: 2026-03-24T18:53:21+00:00

Abstract

To reveal the spatiotemporal differentiation characteristics of the Leaf Area Index (LAI) in Gansu Province and its hydrothermal driving mechanisms, providing a scientific basis for the construction of ecological barriers in arid and semi-arid regions. Based on multi-source remote sensing data from 1981 to 2018, methods such as Sen+MK trend analysis, coefficient of variation, Hurst exponent, sensitivity rate, and contribution rate were employed to systematically analyze the spatiotemporal dynamics and driving mechanisms of LAI across different ecological zones in Gansu Province.

The results indicate that: areas with low multi-year average LAI values (< 0.8) account for 66.47% of the province's vegetation area, concentrated in the central and eastern regions, while the deciduous forest ecological zone of the Qinling Mountains has the highest average value (4.19). LAI shows an increasing trend in 89.88% of the province, with 67.16% showing a significant increase; the annual growth rate of LAI is 0.004, with the most significant growth occurring in the Ordos Plateau grassland ecological zone. LAI fluctuations are significant, with medium-to-high fluctuation areas accounting for 75.81%, and the Qaidam semi-desert ecological zone exhibiting the strongest fluctuations.

Furthermore, 88.67% of the region shows sustainable growth potential, with the Ordos grassland having the largest proportion of sustainable growth areas (98.49%). Specific humidity is the dominant driving factor for LAI, with areas where its contribution rate exceeds 60% accounting for 80.77% of the vegetation cover in Gansu Province; LAI exhibits prominent sensitivity to evapotranspiration and precipitation, with high-sensitivity areas mainly distributed in southern Gansu. This study provides quantitative support for the assessment of vegetation restoration potential and differentiated management in the arid regions of Northwest China.

Full Text

Spatiotemporal Evolution of Vegetation Leaf Area Index in Gansu Province and its Hydrothermal Driving Mechanisms

Zheng Sanjun, Ma Jianmin, Zhou Xing, Wang Zhengxiong *(Gansu Surveying and Mapping Engineering Institute, Lanzhou 730051, China)*

Abstract

This study aims to reveal the spatiotemporal differentiation characteristics of the Leaf Area Index (LAI) in Gansu Province and its hydrothermal driving mechanisms, providing a scientific basis for ecological protection and high-quality development in arid and semi-arid regions. Based on the Global Land Surface Satellite (GLASS) LAI dataset from 2001 to 2020, we analyzed the spatiotemporal evolution of vegetation LAI in Gansu Province using methods such as Theil-Sen median trend analysis, the Mann-Kendall test, and coefficient of variation analysis. Furthermore, we employed the Geodetector model to quantify the driving effects of precipitation and temperature on LAI changes.

The results indicate that: (1) From 2001 to 2020, the vegetation LAI in Gansu Province exhibited a significant upward trend, with a growth rate of 0.004 a^{-1}. Spatially, the LAI showed a distribution pattern of "high in the southeast and low in the northwest." (2) Approximately 88.4% of the study area showed an increasing trend in LAI, with significant improvements observed in the Loess Plateau region of eastern Gansu. The coefficient of variation analysis suggests that vegetation stability is generally high, although some areas in the Hexi Corridor exhibit high volatility. (3) Geodetector analysis reveals that both precipitation and temperature are primary drivers of LAI spatial distribution, with precipitation exerting a stronger explanatory power in most regions. The interaction between precipitation and temperature significantly enhances the impact on vegetation growth compared to individual factors. These findings highlight the critical role of hydrothermal conditions in governing vegetation dynamics and offer insights for regional environmental management under climate change.

1. Introduction

Vegetation serves as a bridge connecting the atmosphere, soil, and water, playing an indispensable role in the global carbon cycle and energy exchange. Gansu Province, located at the intersection of the Loess Plateau, the Qinghai-Tibet Plateau, and the Inner Mongolian Plateau, possesses a complex topography and diverse climatic conditions. Due to its unique geographical location, the region's ecological environment is highly sensitive to climate change.

The Leaf Area Index (LAI) is defined as the total one-sided green leaf area per unit ground surface area. It is a key variable in modeling photosynthesis, transpiration, and energy balance. Understanding the spatiotemporal variations of LAI is essential for monitoring environmental changes and predicting the response of ecosystems to future climate scenarios. While previous studies have focused on vegetation indices such as NDVI, LAI provides a more direct physical representation of the vegetation canopy structure.

In recent decades, under the dual influence of global warming and large-scale ecological restoration projects (such as the "Grain for Green" program), the vegetation cover in Gansu has undergone significant transformations. However, the specific contributions of climatic factors and human activities to these LAI variations, as well as the sensitivity of different vegetation types to environmental drivers, remain subjects of ongoing academic inquiry.

---

2. Materials and Methods

2.1 Study Area

Gansu Province is situated in the upper reaches of the Yellow River and the inland river basins of Northwest China (92°13′–108°46′ E, 32°11′–42°57′ N), with a total area of 42.58×10^4 km^2. The region is characterized by a narrow, elongated geography with elevations ranging significantly from south to north. The climate transitions from a subtropical monsoon climate in the southeast to a temperate continental arid climate in the northwest. This climatic gradient results in a diverse distribution of vegetation types, including forests, grasslands, and desert vegetation.

2.2 Data Sources and Preprocessing

The primary dataset used in this study is the Global Land Surface Satellite (GLASS) LAI product (1981–2018), which features a spatial resolution of 0.05° and an 8-day temporal resolution. This product is generated using general regression neural networks (GRNNs) to ensure long-term consistency.

The driver datasets were obtained from the Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS). This comprehensive dataset includes several key variables: evapotranspiration, air temperature, precipitation, specific humidity, and soil moisture. All data were resampled to a uniform spatial resolution of 0.05° using ArcPy 10.2 to ensure spatial consistency.

2.3 Research Methodology

2.3.1 Trend Analysis and Significance Test Theil-Sen Median trend analysis was used to calculate the rate of change in LAI over time. This method is robust against outliers and non-normal distributions:

$$\beta = \text{Median}\left(\frac{x_j - x_i}{j - i}\right), \forall j > i$$

The significance of the trend was evaluated using the Mann-Kendall (MK) test. The test statistic Z determines the significance level:

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

A trend is considered significant at the 95% confidence level if $|Z| > 1.96$.

2.3.2 Coefficient of Variation The degree of interannual variation was calculated using the coefficient of variation (C_v):

$$C_{vLAI} = \frac{\sigma_{LAI}}{\overline{LAI}}$$

where σ_{LAI} is the standard deviation and $\overline{LAI}$ is the multi-year mean.

2.3.3 Hurst Exponent The Hurst exponent (H) was calculated using Rescaled Range (R/S) analysis to characterize the sustainability of LAI trends. $H > 0.5$ indicates persistence (future trends consistent with the past), while $H < 0.5$ indicates anti-persistence.

2.3.4 Sensitivity and Contribution Analysis The sensitivity (SR) of LAI to driving factors was defined as:

$$SR = \frac{\sum(DF_i - \overline{DF})(LAI_i - \overline{LAI})}{\sum(DF_i - \overline{DF})^2} \times \frac{\overline{LAI}}{\overline{DF}}$$

The contribution rate (CR) was calculated as:

$$CR = \Delta DF \times SR \times 100\%$$

where ΔDF represents the relative change of the influencing factor.

---

3. Results and Analysis

3.1 Spatiotemporal Dynamics of LAI

Overall, the multi-year mean LAI of vegetation in Gansu Province is relatively low. Areas with a mean LAI below 0.8 account for 66.47% of the total vegetation cover, primarily in the central and eastern regions. The highest mean

Figure 2

Figure 1: Figure 2

Figure 4

Figure 2: Figure 4

value (4.19) was observed in the deciduous forest ecological zone of the Qinling Mountains, followed by the Qilian Mountains coniferous forest (3.45).

From 1981 to 2018, 89.88% of the province showed an increasing trend in LAI. Significant increases ($|Z| \geq 1.96$) accounted for 67.16% of the area. The Ordos Plateau grassland exhibited the most rapid growth rate (0.0064 a^{-1}), while the Qaidam Basin semi-desert showed the slowest growth (0.0009 a^{-1}).

3.2 Stability and Sustainability

Stability analysis shows that medium-to-high fluctuation zones account for 75.81% of the total area. Low-fluctuation areas are concentrated in the southern and southeastern regions. Sustainability analysis indicates that 88.67% of the region demonstrates potential for continued growth ($H > 0.5$), with the Ordos Steppe showing the highest proportion of sustainable increases.

3.3 Hydrothermal Driving Mechanisms

Specific humidity was identified as the dominant driving factor, with its contribution rate exceeding 60% across 80.77% of the vegetation cover. LAI also exhibits high sensitivity to evapotranspiration and precipitation, particularly in the southern regions. In the arid Alxa Plateau and Qaidam Basin, extreme scarcity of water resources (precipitation < 150 mm) remains the primary constraint on vegetation development.

Ecoregion	LAI Trend (a^{-1})	Annual Precip (mm)	Specific Humidity ($g \cdot kg^{-1}$)
Ordos Plateau Steppe	0.0064	460.28	1.81
Alxa Plateau Semi-desert	0.0045	< 150	< 0.75
Qaidam Basin Semi-desert	0.0009	Low	Low

Figure 1

Figure 3: Figure 1

Figure 3

Figure 4: Figure 3

4. Conclusion

Vegetation LAI in Gansu Province has significantly improved over the past four decades, characterized by a "greening" trend. This evolution is primarily driven by hydrothermal conditions, with specific humidity and precipitation playing decisive roles. Ecological restoration projects have further bolstered this trend in the Loess Plateau. These findings provide quantitative support for implementing differentiated management strategies in the ecologically fragile regions of Northwest China.

Figures

Source: ChinaXiv —Machine translation. Verify with original.

Figure 5

Figure 5: Figure 5