Spatiotemporal Variations in Vegetation Ecological Quality and Their Driving Mechanisms in the Aksu Region: Postprint

Authors: Fang He

Date: 2023-01-17T00:00:00+00:00

Abstract

Vegetation ecological quality is an important indicator for evaluating terrestrial ecosystems, and investigating spatiotemporal evolution patterns of vegetation quality conditions using remote sensing technology holds important reference value for ecological civilization construction. As a typical climate change-sensitive region and ecologically fragile area in China, the Aksu region is of significant practical importance for studying its vegetation ecological status. This study integrates multi-source remote sensing data and meteorological observation data to explore the spatiotemporal variations in vegetation ecological quality during the growing season (May-September) from 2000 to 2021 in the Aksu region and its responses to climate change and human activities. The results indicate: (1) From 2000 to 2021, vegetation coverage and net primary productivity in the Aksu region exhibited increasing trends, with vegetation "greenness" showing significant improvement; (2) From 2000 to 2021, vegetation ecological quality in the Aksu region demonstrated a steady upward trend, with the area of regions exhibiting improved vegetation ecological quality expanding significantly in desert and bare land areas at oasis margins; (3) Human activities constituted the dominant factor driving changes in the Vegetation Ecological Quality Index (VEQI) across most of the Aksu region, whereas climate change dominated VEQI variations only in limited areas such as the northern part of Wensu County. This study employs multiple vegetation ecological parameters to analyze the spatiotemporal changes in vegetation ecological quality and its driving factors in the Aksu region over the past 22 years, which can provide a data foundation and technical support for regional ecological civilization construction.

ChinaRxiv 中X

Full Text

Spatiotemporal Variation of Vegetation Ecological Quality and Its Driving Mechanism in Aksu Prefecture

FANG He[1,2], YAN Peiwen[2,3], SHI Jian[2,4], KANG Juan[2], LIU Hairong[2], CHEN Dan[2], LUO Ji[2], XU Dong[5]

[1] Zhejiang Climate Center, Hangzhou, Zhejiang 310017, China
[2] Aksu Prefecture Meteorological Administration, Aksu, Xinjiang 843000, China
[3] Shaoxing Meteorological Administration, Shaoxing, Zhejiang 312000, China
[4] Zhuji Meteorological Administration, Zhuji, Zhejiang 311800, China
[5] State Key Laboratory of Remote Sensing Science, Beijing Normal University, Beijing 100875, China

Abstract

Vegetation ecological quality serves as a crucial indicator for evaluating terrestrial ecosystems, and applying remote sensing technology to investigate the spatiotemporal evolution of vegetation quality holds significant reference value for ecological civilization construction. As a typical climate-sensitive region and ecologically fragile area in China, studying the vegetation ecological status in Aksu prefecture carries important practical significance. This study combines multi-source remote sensing data with meteorological observations to explore the spatiotemporal variations of vegetation ecological quality during the growing season (July–September) from 2000 to 2021 and their responses to climate change and human activities. The results demonstrate: (1) Fractional vegetation cover (FVC) and net primary productivity (NPP) exhibited increasing trends, with vegetation "greenness" showing significant improvement; (2) Vegetation ecological quality displayed a fluctuating upward trend from 2000 to 2020, with notable expansion of improved areas in desert and bare land regions at oasis edges; (3) Human activities constitute the dominant factor driving vegetation ecological quality index (VEQI) changes across most of Aksu, while climate change dominates only in small areas such as northern Wensu County. By analyzing multiple vegetation ecological parameters, this study provides a data foundation and technical support for ecological civilization construction in Aksu and similar regions.

Keywords: Net Primary Productivity; Vegetation Coverage; Vegetation Ecological Quality; Spatiotemporal Distribution; Aksu Prefecture

---

1 Introduction

Vegetation ecological quality represents the material foundation for maintaining biodiversity stability and plays a vital role in ecosystem balance and self-regulation. Global vegetation shows a significant greening trend, with China contributing nearly 25% of this effect—the highest proportion worldwide. This contribution partly stems from ecological restoration projects in northwestern China, which has the most extensive distribution of desertified and sandy land in the country. Sustained ecological governance efforts have brought "green" transformation to this region. However, rapid urbanization in cities such as Alar and Aksu over recent decades has promoted large-scale expansion of construction land, profoundly impacting regional ecosystem services and posing substantial threats to biodiversity maintenance. Therefore, investigating the spatiotemporal variation patterns of vegetation ecological quality in Aksu and their responses to climate change and human activities holds significant importance for regional ecological civilization construction.

Satellite remote sensing surveys offer broad coverage, high viewpoints, rapid data acquisition, and continuous, repeatable observations, making them one of the most important means for obtaining surface information. In recent years, rapid development of remote sensing sensors and gradual improvement of earth observation systems have greatly advanced vegetation ecological monitoring research at large scales. Net Primary Productivity (NPP) and fractional vegetation cover (FVC) serve as two key parameters characterizing terrestrial ecosystem service functions and vegetation ecological quality, commonly employed by researchers for regional vegetation ecological quality assessment.

As a crucial factor measuring carbon sources and sinks in earth ecosystems, vegetation NPP characterizes the production potential of ecosystem vegetation under natural conditions. Research on NPP has progressed from early site observations to current large-scale and even global model estimations. Methods based on remote sensing satellite data and meteorological observations have become the primary approach for obtaining large-scale NPP. Meanwhile, FVC measurement methods are mainly divided into ground-based measurements and remote sensing inversion. Remote sensing inversion offers advantages of spatial continuity, wide monitoring range, and low economic cost, making it widely applicable for large-scale vegetation cover monitoring.

Vegetation ecological quality assessment models based on NPP and FVC have achieved considerable development. For instance, researchers have constructed ecological meteorological monitoring and evaluation index models using NPP and FVC, providing effective methods for ecological meteorological monitoring. Other studies have selected multiple indicators including vegetation cover, leaf area index, and thermal conditions to assess vegetation ecological quality in Tibet using principal component analysis, revealing an overall improvement trend from 2006 to 2016. However, previous research on vegetation ecological conditions in Aksu has primarily relied on single parameters, lacking dynamic monitoring that integrates both vegetation cover and NPP into a comprehensive vegetation ecological quality index. This study builds upon established models to investigate the spatiotemporal variation characteristics of vegetation ecological quality in Aksu from 2000 to 2021 and its responses to climatic factors and human activities, offering important insights for ecological civilization construction in Aksu and other regions.

2 Study Area and Methods

2.1 Study Area

Aksu prefecture is located in central Xinjiang, at the southern foothills of the central Tianshan Mountains and the northern Tarim Basin, geographically positioned between 39°30 -42°41 N and 78°03 -84°07 E, with a total area of 13.25$×10^{4}$ km^2. The terrain features higher elevation in the north and lower in the south, with numerous mountain peaks in the north and China' s largest desert—the Taklamakan Desert—in the south. Aksu City belongs to a warm temperate arid climate zone, characterized by dry conditions, perennial water scarcity, high evaporation, long sunshine duration (annual sunshine hours of 2800–3000 h), and a frost-free period of 200–220 days per year.

2.2 Data Sources

Satellite remote sensing data were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) database, including MOD13Q1 NDVI composite products with a spatial resolution of 250 m and temporal resolution of 16 days. Post-processing included mosaicking and projection conversion by the National Meteorological Satellite Center, followed by annual composition using the maximum value synthesis method to characterize annual vegetation growth conditions. Digital elevation model data were derived from the United States Geological Survey. Concurrent meteorological observation data were provided by the Aksu Prefecture Meteorological Administration, including daily temperature and precipitation data from meteorological stations with complete monthly records, which were synthesized into monthly and annual mean values.

2.3 Methods

2.3.1 NPP Estimation NPP was estimated using MODIS NDVI composite products and concurrent meteorological observations through the Terrestrial Ecosystem Carbon Flux (TECF) model provided by the National Meteorological Center:

$$NPP = GPP - R_a$$

where R_a represents assimilated products consumed by autotrophic respiration, calculated as:

$$R_a = 1 \times (7.825 + 1.145 \times T_a/100)$$

with T_a being monthly mean temperature. Gross Primary Productivity (GPP) is calculated as:

$$GPP = \varepsilon^* \times T_\varepsilon \times W_\varepsilon \times FPAR \times PAR$$

where ε^* is maximum light use efficiency, T_ε is temperature stress factor, W_ε is water stress factor, and $FPAR$ is the fraction of photosynthetically active radiation absorbed by vegetation. Detailed parameter calculation methods and values can be found in relevant literature.

2.3.2 Fractional Vegetation Cover Estimation FVC was calculated from monthly MODIS NDVI composite data using the mixed-pixel decomposition method:

$$FVC = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}$$

where $NDVI_{soil}$ represents NDVI for pure bare soil pixels and $NDVI_{veg}$ represents NDVI for pure vegetation pixels. Based on China' s vegetation characteristics, this study adopted values of 0.05 and 0.70 for $NDVI_{soil}$ and $NDVI_{veg}$, respectively.

2.3.3 Vegetation Ecological Quality Index Estimation The Vegetation Ecological Quality Index (VEQI) comprehensively reflects vegetation ecological quality by analyzing the importance of vegetation cover and NPP using a weighted approach. It represents the combined capacity of vegetation cover and production per unit area:

$$VEQI = 100 \times (f_1 \times FVC + f_2 \times \frac{NPP}{NPP_{max}})$$

where f_1 and f_2 are weighting coefficients (both 0.5 in this study), and NPP_{max} represents the maximum NPP value during the study period under optimal local meteorological conditions. VEQI ranges from 0 to 100, with higher values indicating better vegetation ecological quality.

2.3.4 Multiple Regression Residual Analysis Climate factors (temperature, precipitation) and human activities are important drivers of interannual vegetation ecological quality variation. This study employed multiple linear regression residual analysis to investigate their relative contributions, involving three steps: (1) Establishing a multiple linear regression model with temperature and precipitation raster data as independent variables and VEQI as the dependent variable; (2) Calculating simulated VEQI values based on the regression model and climate data to represent climate factor impacts; (3) Using residuals between observed and simulated VEQI to characterize human activity impacts.

3 Results and Analysis

3.1 Spatiotemporal Changes in NDVI and FVC

From 2000 to 2021, annual mean NDVI in Aksu showed a significant increasing trend (Figure 1), growing at a rate of 0.024 per decade. Interannual FVC also exhibited an upward trend, increasing by approximately 0.25% annually. The lowest FVC occurred in 2000 at 8.25%, while the highest reached 14.23% in 2021, with a mean value of 8.75%.

Spatially, vegetation NDVI distribution showed an overall improvement (Figure 2). High-value areas were primarily located in Alar City, central-eastern Wushi County, northern Awati County, southern Wensu County, southern Baicheng County, and the intersection region of Xinhe, Kuqa, and Shaya counties, with values mostly between 0.5 and 0.7. Low-value areas appeared in desert, bare land, and Gobi regions across various counties. Over 90% of the region showed increasing NDVI trends, with the most significant growth in southern Wensu County, northern Alar City, central Aksu City, and the intersection area of Xinhe, Shaya, and Kuqa counties, with growth rates of 0.02–0.04 per year.

Vegetation cover distribution also showed overall improvement (Figure 3). The area of high FVC expanded significantly, with the most pronounced growth in southern Wensu County, northern Alar City, central Aksu City, eastern Xinhe County, and central-northern Kuqa County, with annual growth rates of 2–4%. Even in desert areas, FVC showed growth trends, albeit slower (below 2% per year). Declining FVC areas were mainly located in southern Aksu City and northern Wensu County desert regions, with average decreases of 1-2% per year.

3.2 Vegetation NPP

Vegetation net primary productivity represents the remaining organic dry matter after subtracting autotrophic respiration from photosynthetic production. As a key variable characterizing vegetation vitality, NPP forms the basis of ecosystem energy and material cycles and reflects carbon sequestration capacity.

From 2000 to 2021, annual cumulative NPP in Aksu showed a gradual upward trend (Figure 4), increasing by approximately 0.62 $g \cdot m^{-2} \cdot a^{-1}$. The lowest mean NPP was 306.45 $g \cdot m^{-2}$ in 2000, while the highest reached 340.25 $g \cdot m^{-2}$ in 2021. Concurrently, vegetation oxygen release also showed continuous growth, increasing from 50.82 $g \cdot m^{-2}$ in 2000 to 79.16 $g \cdot m^{-2}$ in 2021 at a rate of 1.65 $g \cdot m^{-2} \cdot a^{-1}$.

Spatially (Figure 5), over 85% of the region showed increasing NPP trends, with the most significant growth in Alar City, central-eastern Wushi County, northern Awati County, southern Wensu County, southern Baicheng County, and the intersection region of Xinhe, Kuqa, and Shaya counties, with average increases of 5-7 $g \cdot m^{-2} \cdot a^{-1}$. Declining NPP areas were mainly in northern

Wensu County, northern Baicheng County, eastern Kuqa County, and parts of northern Shaya County, with average decreases of 0–2 $g \cdot m^{-2} \cdot a^{-1}$.

3.3 Vegetation Ecological Quality

While NPP and FVC are two key characteristics reflecting terrestrial ecosystem services and vegetation ecological quality, using either parameter alone can only reflect one aspect—production capacity or cover capacity. The integrated VEQI constructed in this study reflects the combined capacity of vegetation production and cover per unit area, resolving issues where NPP values are identical but surface coverage differs, or where coverage is identical but NPP varies.

From 2000 to 2021, the interannual VEQI in Aksu showed a steady upward trend (Figure 6), increasing by approximately 0.42 annually. The lowest VEQI was 28.45 in 2000, while the highest reached 38.67 in 2021, with a mean value of 33.45 indicating relatively good vegetation ecological quality.

Spatially (Figure 7), VEQI distribution showed overall improvement, with high-value areas primarily in Alar City, central-eastern Wushi County, northern Awati County, southern Wensu County, and southern Baicheng County, with values above 40. The intersection region of Xinhe, Kuqa, and Shaya counties showed VEQI values mostly between 30 and 40. Low-value areas were mainly in desert, bare land, and Gobi regions across various counties, with VEQI below 20. Over 85% of the region showed increasing VEQI trends, with the most significant growth in southern Wensu County, central Alar City, and central Xinhe County, increasing by 0.5–1.0 annually. Desert and Gobi regions also showed VEQI growth, though slower (0–0.5 per year). Declining VEQI areas were mainly in northern Wensu County and eastern Kuqa City, decreasing by 0.2–0.5 annually.

3.4 Response of VEQI to Climate Change and Human Activities

Climate change and human activities jointly influence vegetation ecological quality dynamics in Aksu. Using multiple linear regression residual analysis, we examined their relative contributions (Figure 8). The results show that under human activity influence, VEQI showed significant improvement across most areas from 2000 to 2021, with notable enhancement in existing green spaces and significant expansion of improved areas in desert and bare land regions at oasis edges.

The dominant factor for VEQI changes across approximately 92% of Aksu is human activities, with climate change contributions being relatively small in most areas. Only in small regions such as northern Wensu County did climate change dominate VEQI variation. This indicates that ecological restoration projects implemented since 2000, particularly after the launch of the "Returning Grazing to Grassland" project in 2003 and the iconic "Kekeya Greening Project" recognized by the UN as one of the "Global 500 Roll of Honour, have been instrumental in improving vegetation ecological quality.

4 Discussion

Aksu prefecture features a typical warm temperate arid climate with scarce precipitation, high evaporation, and dry conditions, making it one of Xinjiang' s sandstorm source areas and a typical climate-sensitive and ecologically fragile region in China. Vegetation ecological quality dynamics are primarily influenced by the combined effects of human activities and climate change, with temperature and precipitation playing crucial roles in vegetation growth.

Since 2003, supported by national and autonomous region initiatives, Aksu has vigorously implemented ecological restoration and management projects. Guided by the "Two Mountains" theory, the region has forged an innovative path of ecological priority and green development with Aksu characteristics. The most representative project is the Kekeya Greening Project, recognized by the United Nations as one of the "Global 500 Roll of Honour. Landsat imagery comparisons between 2000 and 2021 (Figure 9) clearly show significantly increased vegetation area and substantially improved regional" greenness" in the Kekeya project area and surrounding regions.

This study provides a comprehensive assessment of vegetation ecological quality in Aksu based on multi-source remote sensing data and meteorological observations. Future research will utilize higher-resolution satellite imagery for more refined vegetation ecological monitoring and analysis, providing data foundations and technical support for ecological protection in Aksu and throughout northwestern China.

5 Conclusion

Under the dual influence of climate change and human activities, vegetation ecological quality in Aksu prefecture has undergone significant changes. Based on multi-source remote sensing data and station observations, we analyzed the spatiotemporal distribution characteristics and driving factors of vegetation ecological quality from 2000 to 2021, reaching the following main conclusions:

1. Most areas of Aksu (approximately 85% of the region) showed increasing trends in annual mean NDVI, FVC, and NPP during the growing season from 2000 to 2021. NDVI increased at a rate of 0.024 per decade, FVC increased at 0.25% per year, and NPP increased at 0.62 $g \cdot m^{-2} \cdot a^{-1}$. Spatially, this manifested as shrinking desert and bare land areas at oasis edges and significant expansion of vegetation-covered areas.
2. Vegetation ecological quality across most of Aksu (approximately 85% of the region) showed a steady upward trend, increasing by about 0.42 annually. The dominant factor for VEQI changes in approximately 92% of the region is human activities, with climate change dominating only in small areas such as northern Wensu County.

These findings provide essential data foundations and technical support for ecological civilization construction in Aksu prefecture and similar regions.

References

[1] Chen C, Park T, Wang X, et al. China and India lead in greening of the world through land use management[J]. Nature Sustainability, 2019, 2(2): 122-129.

[2] Cao Y X, Mao D L, Xue J, et al. Dynamic changes and driving factors of vegetation cover in the oasis-desert ecotone: A case study of Cele, Xinjiang[J]. Arid Zone Research, 2022, 39(2): 510-521.

[3] Maluda Aablikem. Spatial and Temporal Distribution Characteristics of Ecological Hazards and Its Alleviation along the Upper Reaches of Tarim River: Case Study in Aksu[D]. Urumqi: Xinjiang University, 2013.

[4] Xu L J, Wei Q, Xu J Z, et al. Inconsistency of the trend of rainfall and relative humidity in arid regions of northern China[J]. Chinese Journal of Water Resources and Water Engineering, 2021, 32(2): 38-44.

[5] Wang L, Xie X Q, Su W, et al. Variation of the highest and lowest temperature in northern China in the past 50 years and its impact[J]. Journal of Natural Resources, 2004, 19(3): 337-343.

[6] Gong C L. Natural Capital and Ecosystem Service Value Accounting of Land Use Change in Aksu Area[D]. Alar: Tarim University, 2021.

[7] Steffen W, Broadgate W, Deutsch L, et al. The trajectory of the Anthropocene: The great acceleration[J]. The Anthropocene Review, 2015, 2(1): 81-98.

[8] Guo E, Liu X, Zhang J, et al. Assessing spatiotemporal variation of drought and its impact on maize yield in Northeast China[J]. Journal of Hydrology, 2017: 231-247.

[9] Fang H, Xie T, Zhou Y F, et al. Evaluation of SAR wind speed retrieved based on C-2PO model and CMOD5.N geophysical model functions[J]. Haiyang Xuebao, 2018, 40(9): 103-112.

[10] Mao L X, Li C S, Hou Y Y, et al. National ecological meteorological monitoring and evaluation research in the first half of 2006[J]. Meteorology, 2006, 32(12): 105-112.

[11] Mao L X, Qian S, Hou Y Y, et al. Eco-meteorological monitoring and assessment of high temperature and drought in Sichuan and Chongqing in the summer of 2006[J]. Meteorology, 2007(3): 83-88.

[12] Qian S, Mao L X, Hou Y Y, et al. Comprehensive monitoring and prediction technology of ecological meteorology in northern grassland and its application[J]. Meteorology, 2008(11): 62-68.

[13] Wu Y J, Zhao X S, Xi Y, et al. Comprehensive evaluation of Tibet' s ecological quality and its temporal and spatial changes based on MODIS from 2006 to 2016[J]. Acta Geographica Sinica, 2019, 74(7): 1438-1449.

[14] Yang H T, Xu H Q. Vegetation coverage change and ecological quality assessment in Wuyishan National Nature Reserve based on remote sensing spatial information[J]. Chinese Journal of Applied Ecology, 2020, 31(2): 187-196.

[15] Cui C, Guo Y, Shen Y J. Temporal and spatial distribution changes of desert vegetation in Xinjiang and its driving factors[J]. Chinese Journal of Ecological Agriculture, 2021, 29(10): 1668-1678.

[16] Wang Z C, Liu X H, Jia F S, et al. Temporal and spatial evolution characteristics and influencing factors of vegetation cover in the Aksu River Basin in the past 10 years[J]. Journal of Yangtze River Scientific Research Institute, 2017, 34(9): 24-28, 35.

[17] Li Z Y, Yan H, Wu M X, et al. Dynamic monitoring and evaluation model for temporal and spatial changes of vegetation comprehensive ecological quality[J]. Acta Ecologica Sinica, 2020, 40(18): 6573-6583.

[18] Zhao M M, Liu Y, Yang J L, et al. Temporal and spatial variation characteristics of vegetation NPP in China based on HASM and its relationship with climate[J]. Ecology and Environmental Sciences, 2019, 28(2): 215-225.

[19] Jia J H, Liu H Y, Lin Z S. Multi-time scale variation of vegetation NPP in Northwest China and its response to climate change[J]. Acta Ecologica Sinica, 2019, 39(14): 5058-5069.

[20] Liu C, Dong X, Liu Y. Changes of NPP and their relationship to climate factors based on the transformation of different scales in Gansu, China[J]. Catena, 2015, 125: 190-199.

[21] Chen S T, Guo B, Yang F, et al. Temporal and spatial variation pattern of vegetation NPP on the Qinghai-Tibet Plateau and its response to climate change from 2000 to 2015[J]. Journal of Natural Resources, 2020, 35(10): 2511-2527.

[22] Zhou W, Gang C C, Li J L, et al. Temporal and spatial dynamics of grassland coverage in China from 1982 to 2010 and its response to climate change[J]. Acta Geographica Sinica, 2014, 69(1): 15-30.

[23] Li H X, Liu G H, Fu B J. Responses of vegetation growth to climate change and human activities in the Three River Headwaters based on NDVI[J]. Acta Ecologica Sinica, 2011, 31(19): 5495-5504.

[24] Jin K, Wang F, Han J Q, et al. Effects of climate change and human activities on vegetation NDVI changes in China from 1982 to 2015[J]. Acta Geographica Sinica, 2020, 75(5): 961-974.

[25] Yi L, Ren Z Y, Zhang C, et al. The relationship between vegetation cover change and climate and human activities on the Loess Plateau[J]. Resources Science, 2014, 36(1): 166-174.

[26] Xu D, Yang F, Yu L, et al. Quantization of the coupling mechanism between eco-environmental quality and urbanization from multisource remote sensing

data[J]. Journal of Cleaner Production, 2021: 128948.

[27] Cao Y, Qian Y L, Sun Y L, et al. Analysis of temporal and spatial variation characteristics of forest vegetation in Southwest China and its climate response based on MODIS NDVI[J]. Ecology and Environmental Sciences, 2020, 29(5): 857-865.

[28] Liu H Y, Zhang M Y, Lin Z S, et al. Spatial heterogeneity of the relationship between vegetation dynamics and climate change and their driving forces at multiple time scales in Southwest China[J]. Agricultural and Forest Meteorology, 2018, 256: 10-21.

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