

## Impacts of Climate Change and Human Activities on Vegetation Coverage in the Xilingol Grassland (Postprint)

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### Abstract

Based on remote sensing, meteorological, and statistical data, and employing linear trend analysis and residual analysis methods, the dynamics of grassland vegetation coverage in the Xilingol Grassland from 1982 to 2018 were monitored at different spatiotemporal scales, and the contribution rates of climate change and human activities to vegetation changes were quantified. The results show that from 1982 to 2018, vegetation coverage and its changes in the Xilingol Grassland exhibited significant spatial heterogeneity, with meadow steppe coverage showing a significant increasing trend ( $P < 0.01$ ) and desert steppe coverage showing a significant decreasing trend ( $P < 0.01$ ). The year 2000 was the main turning point for grassland coverage changes at the banner/county level. Human activities were the dominant factor driving vegetation dynamics in the Xilingol Grassland, with the comprehensive contribution rate of human activity factors in the study area being 65.06% over the years. Vegetation in parts of the central-eastern and southern regions was significantly improved under positive human influences, while vegetation in the western and northern desert steppe areas continued to show degradation trends. It is recommended to strengthen the implementation of ecological policies in desert steppe areas to ensure the sustainability of grassland ecosystems.

### Full Text

#### Abstract

Based on remote sensing, meteorological, and statistical data, this study employs linear trend analysis and residual analysis methods to monitor the dynamics of grassland fractional vegetation cover (FVC) in the Xilingol steppe across different spatial and temporal scales, and to quantify the contribution rates of climate change and human activities to vegetation change. The results

indicate that vegetation cover and its changes in the Xilingol steppe exhibit significant spatial heterogeneity. Meadow steppe coverage shows a significant increasing trend ( $P < 0.01$ ), while desert steppe coverage shows a significant decreasing trend ( $P < 0.01$ ). The year 2000 represents a major turning point for FVC changes at the banner level. Human activities constitute the dominant factor driving vegetation dynamics in the Xilingol steppe, with a comprehensive contribution rate of 65.06% across the study area. Vegetation in parts of the central-eastern and southern regions has improved significantly under positive human intervention, while vegetation in the western and northern desert steppe areas continues to show degradation trends. We recommend intensifying ecological policy implementation in desert steppe regions to ensure the sustainability of grassland ecosystems.

**Keywords:** vegetation coverage; climate; human activities; residual analysis; contribution rate; Xilingol steppe

## 1.1 Study Area Overview

The Xilingol League is located in central Inner Mongolia (119°58 E–111°09 E, 41°35 N–46°46 N) and represents the nearest grassland pastoral area to the Beijing-Tianjin economic circle, serving as a nationally important livestock product base [Figure 1: see original paper]. The region experiences a temperate arid and semi-arid continental monsoon climate, with a multi-year average annual precipitation of 265.55 mm concentrated primarily in the growing season. The average annual temperature shows a fluctuating upward trend at a rate of 0.48°C per decade, with a multi-year mean of 2.33°C. Both annual precipitation and temperature exhibit spatial variation within the region, with precipitation increasing from northwest to southeast while temperature gradually decreases from west to northeast. The study area is rich in grassland resources, with a total grassland area of  $1.93 \times 10^5 \text{ km}^2$ , accounting for 97.2% of the total land area. From east to west, the grassland types transition through meadow steppe, typical steppe, and desert steppe. Plant communities are dominated by xerophytic bunchgrasses such as *Stipa grandis* and *Stipa baicalensis* [15]. The Xilingol League governs nine banners and counties with a permanent population of  $1.05 \times 10^6$  at the end of 2018. The southern region has higher population density. In 2018, the total output value of agriculture. Among these, Taibus Banner and Duolun County have relatively larger agricultural output proportions, while East Ujimqin Banner, West Ujimqin Banner, Sunit Left Banner, and Sunit Right Banner have larger animal husbandry output proportions.

## 1.2 Data Sources

The Normalized Difference Vegetation Index (NDVI) data for the growing season (April–October) from 1982 to 2018 were obtained from two sources. The GIMMS-NDVI dataset (1982–2015) was downloaded from the NASA website ([adsweb.nascom.nasa.gov/](http://adsweb.nascom.nasa.gov/)), with a spatial resolution of 8 km and temporal

resolution of 15 days. The MOD13A1 NDVI dataset (2000–2018) was provided by NASA with a spatial resolution of 500 m and temporal resolution of 16 days. Both datasets underwent preprocessing including mosaicking and projection using MODIS Reprojection Tool software [16]. Due to the different sensors used for GIMMS and MODIS NDVI data, and referencing relevant research [17], we used regression equations to correct and fuse the two datasets based on overlapping years ( $r^2 = 0.63$ ,  $P < 0.01$ ). Vegetation type data were derived from the vegetation map of China to extract spatial distributions of typical steppe, meadow steppe, and desert steppe [18]. Meteorological data including precipitation and temperature were obtained from the China Meteorological Data Network ([//data.cma.cn](http://data.cma.cn)), using the China Ground Precipitation Monthly Grid Dataset ( $0.5^\circ \times 0.5^\circ$ ) and China Ground Temperature Monthly Grid Dataset ( $0.5^\circ \times 0.5^\circ$ ), which were interpolated using Krigeleveld data on population, large livestock numbers, and grassland area were sourced from the Xilingol League Statistics Bureau.

### 1.3.1 Vegetation Coverage Inversion

The pixel dichotomy model is currently one of the most commonly used methods for retrieving fractional vegetation cover from NDVI data [19–21]. This study employs this method to calculate FVC using the following formula [22]:

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

where  $FVC$  is fractional vegetation cover,  $NDVI_{soil}$  represents the NDVI value for pure bare soil pixels, and  $NDVI_{veg}$  represents the NDVI value for pure vegetation pixels. Following the approach of most scholars,  $NDVI_{soil}$  and  $NDVI_{veg}$  were obtained using the 5% and 95% confidence interval thresholds of the NDVI frequency distribution [23]. Finally, monthly FVC values were averaged to obtain the annual growing season mean. Based on the 1982–2018 grassland FVC data and the vegetation coverage classification standards from the Ministry of Water Resources [24], we obtained the spatial pattern of regional grassland vegetation coverage.

### 1.3.2 Vegetation Coverage Trend Analysis

We used univariate linear regression analysis to monitor the spatiotemporal patterns of regional vegetation coverage change [25], with the formula:

$$slope = \frac{n \sum i \cdot FVC_i - \sum i \sum FVC_i}{n \sum i^2 - (\sum i)^2}$$

where  $slope$  represents the trend slope,  $n$  is the number of study years,  $i$  is the year index, and  $FVC_i$  is the mean growing season vegetation coverage for year  $i$ . When  $slope > 0$ , vegetation coverage shows an increasing trend; when  $slope < 0$ ,

it shows a decreasing trend. Statistical analysis of vegetation coverage change characteristics was conducted at two scales: grassland type and banner level.

### 1.3.3 Identifying Contribution Rates of Climate Change and Human Activities to Vegetation Change

First, correlation analysis was used to determine the relationship between annual total precipitation, mean temperature, and vegetation coverage at the regional scale, with significance of partial correlation coefficients tested using t-tests (calculation methods detailed in reference [26]). Based on this, we employed an improved residual analysis method to identify the impact of human activities on vegetation coverage [27-28]. Using precipitation and temperature data from 1982–2018, we fitted predicted vegetation coverage values and used the difference between predicted and actual values as an indicator of human activity impact. The formula is:

$$\varepsilon = FVC_{real} - FVC_{pre}$$

where  $\varepsilon$  is the residual,  $FVC_{real}$  is the measured vegetation coverage value, and  $FVC_{pre}$  is the predicted vegetation coverage value. When  $\varepsilon > 0$ , human activities have a positive impact on vegetation coverage; when  $\varepsilon < 0$ , they have a negative impact; and when  $\varepsilon = 0$ , human activities have essentially no impact.

Based on the residual analysis results, we calculated the contribution rates of climate change and human activities to vegetation coverage change [29] using:

$$\text{Climate Contribution} = \frac{\text{slope}(FVC_{pre})}{\text{slope}(FVC_{real})} \times 100\%$$

$$\text{Human Activity Contribution} = \frac{\text{slope}(\varepsilon)}{\text{slope}(FVC_{real})} \times 100\%$$

To more intuitively compare the spatial distribution of relative contribution degrees of the two factors, we improved the overly absolute method of dividing dominant factors by trend direction alone, referencing relevant research [30]. We overlaid vegetation coverage change trends with factor contribution rates, defining factors with contribution rates greater than 55% as dominant factors and those with 45%–55% as balanced contributions. The region was thus divided into six categories: climate-dominated negative impact areas, climate-dominated positive impact areas, human activity-dominated negative impact areas, human activity-dominated positive impact areas, combined-factor negative impact areas, and combined-factor positive impact areas.

## 2.1 Spatiotemporal Patterns of Vegetation Coverage (1982–2018)

Vegetation coverage in the Xilingol steppe exhibits significant spatiotemporal heterogeneity. Spatially, vegetation coverage gradually decreases from northeast to southwest, with low-coverage areas are mainly distributed in the western desert steppe belt, while the central typical steppe and eastern meadow steppe have relatively high vegetation coverage [Figure 2: see original paper]. Areas with vegetation coverage less than 30% account for the largest proportion, approximately one-third of the total grassland area, while regions with coverage greater than 70% are the smallest, comprising only 7.16% of the total grassland area and concentrated in the east.

The three grassland types show distinct differences in vegetation coverage change. Meadow steppe has a multi-year average coverage of 56.43% and shows a significant increasing trend ( $P < 0.01$ ). Typical steppe has an average coverage of 47.03% with no significant change over the years. Desert steppe has a multi-year average coverage of 15.29% and shows a significant decreasing trend ( $P < 0.01$ ). At the banner level [Figure 3: see original paper], most banners show obvious changes in vegetation coverage around the year 2000. Sunit Left Banner, Sunit Right Banner, and Erenhot City all show significant decreasing trends ( $P < 0.01$ ), with Erenhot showing the largest decline of 8.78% between the two time periods. Duolun County, Taibus Banner, Zhenglan Banner, West Ujimqin Banner, East Ujimqin Banner ( $P < 0.01$ ), and Xilinhot City ( $P < 0.05$ ) all show significant increasing trends, with increases of 17.19%, 13.98%, 8.70%, 4.93%, and 2.49%, respectively. Abaga Banner, Xianghuang Banner, and Zhengxiangbai Banner show no clear pattern of change.

### 2.2.1 Relationship between Vegetation Coverage and Main Meteorological Factors

Annual precipitation in the study area shows fluctuating patterns with a multi-year average of 265.55 mm, concentrated in the growing season. Mean annual temperature shows a fluctuating upward trend with a multi-year average of 2.33°C. Precipitation demonstrates a significant positive correlation with vegetation coverage ( $P < 0.01$ ), while temperature correlation is not significant. Most areas in the central and western regions show positive correlations between vegetation coverage and precipitation, accounting for 81.57% of the total area [Figure 5: see original paper]. Only a few areas in the east show positive correlations between vegetation coverage and temperature, while negative correlation areas are extensive, distributed from Sunit Right Banner in the west to central East Ujimqin Banner, accounting for 59.50% of the total area. T-test results further confirm the significant correlation between annual precipitation and vegetation coverage, with 46.25% of the area passing the positive correlation significance test. Temperature effects on vegetation coverage are weak across 97.04% of the region.

### 2.2.2 Impact of Human Activities on Vegetation Coverage

The residual trend across the study area shows that human activities have negative impacts in western and central regions (41.50% of area) and positive impacts in eastern and southern regions (39.48% of area) [Figure 6: see original paper]. Comparing pre- and post-2000 periods reveals significant differences in negative or positive impacts of human activities on vegetation across different banners. Before 2000, residual trends were positive in central areas, Sunit Left Banner, and central-west Sunit Right Banner, indicating positive human activity impacts covering approximately 50.26% of the area. However, southern Zhenglan Banner, Duolun County, and eastern East/West Ujimqin Banners showed negative residual trends. After 2000, residual trends became positive in eastern East/West Ujimqin Banners, indicating positive impacts covering about 44.03% of the area, while human activities in western Sunit Left and Right banners showed negative impacts. Overall, the proportion and extent of areas with positive human activity impacts increased after 2000, though local areas, particularly desert steppe zones, still show negative impacts.

### 2.2.3 Contribution Rates of Climate Change and Human Activities to Vegetation Change

The dominant impacts of human activities and climate change show clear spatial heterogeneity, with human activities being the dominant factor in vegetation change across the Xilingol steppe [Figure 7: see original paper]. At the regional scale, the comprehensive contribution rate of climate factors to vegetation coverage change is 34.94%, while that of human activity factors is 65.06%. Spatially, human activity-dominated areas account for 80.98% of the total study area, with positive impacts mainly in the east and south and negative impacts mainly in the west. Climate-dominated impact areas account for only 6.46% of the total area, with positive impact areas (16.97%) scattered in central regions such as Abaga Banner and Xilinhot City. Combined-factor impact areas constitute just 2.04% of the total area.

At the banner level, Zhenglan Banner and East Ujimqin Banner likely experienced positive impacts dominated by human activities, leading to vegetation improvement. Western banners such as Sunit Right Banner and Sunit Left Banner experienced vegetation degradation mainly due to negative impacts dominated by human activities. Central areas like Abaga Banner show complex distributions of multiple factor types, resulting in no significant vegetation coverage change throughout the entire period.

## 3 Discussion

This study assessed grassland vegetation coverage changes and the contributions of influencing factors in the Xilingol steppe, revealing a pattern of overall vegetation coverage increase with local decreases, and no significant overall change—consistent with existing research [31]. The difference lies in that this

study further quantified the contribution rates of climate change and human activities at the banner scale, providing more intuitive insights into the degree, type, and extent of impacts from both factors compared to previous studies, which can help refine policy recommendations for different banners.

Based on our results and comparisons with statistical yearbooks and related research, we can preliminarily analyze the causes of differences in vegetation changes and their driving forces among banners. First, climate factors: precipitation is the main climatic factor affecting vegetation coverage in arid grassland regions, a conclusion consistent with previous studies [32]. Spatially, the climate pattern of high temperature and low precipitation in western study areas is unfavorable for vegetation growth, resulting in lower vegetation coverage in western banners such as Sunit Left Banner, Erenhot City, and Sunit Right Banner (all with multi-year average coverage below 20%). In contrast, Duolun County and Taibus Banner have favorable climate conditions, with multi-year average vegetation coverage reaching approximately 60%. The study also found scattered, discontinuous patchy areas in the east and southeast where vegetation coverage shows significant negative correlation with precipitation. These eastern patchy areas in West Ujimqin Banner show obvious vegetation degradation [11], while southern patchy areas are located in the Hunshandake Sandy Land with aeolian sandy soil that has strong permeability and high surface evaporation. In these areas, excessive precipitation can be detrimental to plant growth due to insufficient light and heat conditions [33]. Areas showing significant negative correlation between vegetation coverage and temperature are mainly in southwestern Sunit Right Banner, where the multi-year average temperature exceeds 4°C with good heat conditions, making water the main limiting factor for vegetation growth—higher temperatures increase evaporation and reduce precipitation, leading to poorer vegetation growth [33].

Grassland ecosystem types and climate change form a feedback mechanism [34]. The Xilingol League has vast grassland areas [15], with forest and cultivated land totaling only 11,228 km<sup>2</sup> (5.71% of total area), so this study focused only on grassland changes. Meadow steppe, typical steppe, and desert steppe are distributed from east to west across the study area. Research by Yang et al. [35] indicates that precipitation use efficiency decreases sequentially across these three grassland types, while Xu et al. [36] suggest that different grassland types result in differences in ecosystem resilience, stability, and ecological vulnerability. East Ujimqin Banner and West Ujimqin Banner are located in meadow steppe areas, while Sunit Left and Right banners are in desert steppe areas. The inherent differences in grassland types lead to different ecosystem structures, resulting in different vegetation coverage. Since desert steppe has low capacity to adapt to climate change, it is more vulnerable to climate impacts [37], explaining why vegetation continues to decrease in western banners with low coverage while coverage significantly increases in southeastern banners.

Human activities such as population growth and livestock development have more extensive impacts on vegetation. Since the 1980s, Xilingol League statis-

tical yearbooks show that registered population numbers have increased significantly. Generally, eastern and western banners have sparse populations while central and southern regions have denser populations. These inter-banner differences in population partially determine differences in human activity impacts [38]. Furthermore, studies show that grazing greatly affects grassland ecosystem structure and function [39]. For example, East and West Ujimqin banners in the east had large livestock numbers of  $3.03 \times 10^5$  and  $2.25 \times 10^5$  head at the end of May, respectively. Due to lush vegetation, good forage quality, and large grassland areas in these regions, reasonable grazing does not easily cause negative impacts on vegetation coverage. In contrast, central-western Abaga Banner, Sunit Left Banner, and Sunit Right Banner had large livestock numbers of  $2.19 \times 10^5$ ,  $1.35 \times 10^5$ , and  $1.42 \times 10^5$  head, respectively. These regions have sparse vegetation and poor grassland recovery capacity, making grazing more likely to negatively impact vegetation coverage and requiring stricter grazing planning policies to reduce grassland damage. Research by Wang et al. [40] confirms this livestock density distribution pattern.

Since 2000, the implementation of the Beijing-Tianjin Sand Source Control Project has intensified grazing management in Xilingol League, with seasonal grazing bans, rotational grazing, and total grazing prohibitions implemented in severely degraded and desertified grassland ecological areas [41], leading to varying degrees of reversal in grassland desertification processes [42]. We also used ordered cluster analysis to verify temporal variation points in vegetation coverage for different banners [43], both confirming 2000 as a significant change node and explaining why human activity impacts shifted from negative to positive after this year. Additionally, the proportion of human activity-dominated impacts exceeds that of climate change, a finding also confirmed in research by Ai et al. [38]. Therefore, future grazing policy formulation should be based on these findings and refined to specific areas within banners. For example, in banners where human activities still have negative impacts and grassland degradation is severe, such as Sunit Left Banner and Sunit Right Banner, ecological policy implementation should be strengthened. Other banners and even smaller areas should implement varying degrees of year-round grazing bans, seasonal grazing bans, grassland-livestock balance policies, and ecological compensation based on actual conditions. For severely degraded desert steppe areas, positive human intervention should be enhanced, such as establishing sand barriers and other windbreak and sand fixation projects.

## 4 Conclusions

- 1) Vegetation coverage in the Xilingol steppe shows obvious spatial heterogeneity, decreasing sequentially from east to west across meadow steppe, typical steppe, and desert steppe. From 1982 to 2018, meadow steppe coverage showed a significant increasing trend, desert steppe showed a significant decreasing trend, while typical steppe showed fluctuating changes. At the administrative level, the year 2000 was an important node for change.

Eastern banners including East Ujimqin Banner, West Ujimqin Banner, Xilinhot City, and southern Taibus Banner and Duolun County showed significant vegetation coverage increases, while western and northern areas including Sunit Right Banner, Sunit Left Banner, and Erenhot City showed significant vegetation coverage decreases.

- 2) Human activities are the dominant factor driving vegetation change in the Xilingol steppe, with regionally differentiated dominant impacts from human activities and climate change. Human activity-dominated impact areas account for 80.98% of the total area, with positive impacts mainly occurring in the east and south, and negative impacts mainly in the west. Refining the analysis of driving force differences in vegetation coverage change within banner-level regions can better inform policy development to protect grasslands and reduce grassland ecosystem risks.

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