Postprint of Ecological Environment Assessment of Xilingol Grassland Based on an Improved Remote Sensing Ecological Index Model

Authors: Song Meijie

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Abstract

The continuous intensification of climate change and human activities has triggered issues of ecological environmental quality. Rapid and accurate assessment of the history and current status of regional ecological environments is of great significance for achieving sustainable and coordinated development between humans and nature. This paper retrieves greenness, humidity, dryness, and heat factors based on remote sensing technology, and constructs a Modified Remote Sensing Ecological Index (MRSEI) using principal component analysis. Using correlation analysis, the representativeness of MRSEI was analyzed, an ecological environment assessment model for the Xilingol Grassland was established based on MRSEI, and a comprehensive evaluation of the ecological environment of the Xilingol Grassland over the past 26 years was conducted. The results show that: MRSEI can integrate information from the four ecological factors and accurately evaluate the ecological environment; the ecological environment quality of the Xilingol Grassland showed a trend of initial improvement followed by deterioration from 1991 to 2017; in 1991, the ecological environment quality in the upstream area of the study region was better than that in the downstream area, and the eastern part was better than the western part; in 2004, the spatial variation of overall ecological environment quality in the study region changed significantly compared to 1991, with most upstream areas showing improved ecological environment quality but a clear decline in the downstream; by 2017, the ecological environment quality across the entire study region had comprehensively declined, with only the banks of the upper Xilin River and the southern and southeastern parts of the basin maintaining good and excellent levels.

Full Text

Abstract

Climate change and human activities continue to intensify, causing ecological and environmental quality problems. It is crucial for the sustainable and coordinated development of human and nature to quickly and accurately evaluate the historical and current status of regional ecological environments. This paper retrieved four indicators including greenness, wetness, dryness, and heat using remote sensing techniques. Principal component analysis (PCA) was employed to construct the modified remote sensing ecological index (MRSEI), and the representativeness of MRSEI was analyzed through correlation analysis. Based on MRSEI, an ecological environment evaluation model was developed for the Xilin Gol Steppe, and a comprehensive assessment of the ecological environment over the past 26 years was conducted. The results showed that MRSEI could effectively integrate information from various ecological factors and accurately evaluate the ecological environment. From 1991 to 2017, the ecological environment quality in the Xilin Gol Steppe initially improved and then degraded. In 1991, the environmental quality in the upstream area was better than that in the downstream area, and better in the eastern part than in the western part. In 2004, the spatial differentiation of overall ecological environmental quality in the study area changed noticeably compared to 1991, with the upstream environment improving while the downstream environment obviously deteriorated. By 2017, the ecological environment quality across the entire study area was generally reduced, and a good ecological environment remained only along the upper banks of the Xilin River and in the southern and southeastern parts of the drainage basin.

Keywords: modified remote sensing ecological index (MRSEI); principal component analysis; ecological factor; environment evaluation; Xilin Gol

2.4 Construction of MRSEI

The modified remote sensing ecological index (MRSEI) was constructed using principal component analysis (PCA). The first principal component (PC1) of the four indicators (NDVI, WET, NDSI, LST) was used to generate MRSEI, which integrates information from each ecological factor. Previous studies have shown that NDVI can indicate vegetation growth status and coverage, WET reflects soil moisture, NDSI represents surface dryness, and LST characterizes heat conditions. The PCA results indicated that PC1 consistently exhibited high loadings for all four indicators across the three time periods, demonstrating its effectiveness in comprehensively representing the ecological environment.

The specific MRSEI models for each year were established as follows:

$$\mathrm{MRSEI}_{1991} = 0.3022 \times \mathrm{NDVI} + 0.2618 \times \mathrm{WET} - 0.2500 \times \mathrm{NDSI} - 0.1860 \times \mathrm{LST} + 0.4360$$
$$\mathrm{MRSEI}_{2004} = 0.3439 \times \mathrm{NDVI} + 0.2580 \times \mathrm{WET} - 0.2248 \times \mathrm{NDSI} - 0.1836 \times \mathrm{LST} + 0.3981$$
$$\mathrm{MRSEI}_{2017} = 0.2608 \times \mathrm{NDVI} + 0.2248 \times \mathrm{WET} - 0.3333 \times \mathrm{NDSI} - 0.2111 \times \mathrm{LST} + 0.5143$$

The loadings show that NDVI and WET contributed positively to MRSEI, while NDSI and LST contributed negatively. The contribution of NDVI was highest in 2004 (0.3439) and lowest in 2017 (0.2608). WET showed a decreasing trend over time ($0.2618 \rightarrow 0.2580 \rightarrow 0.2248$). The negative impact of NDSI increased significantly in 2017 (-0.3333) compared to previous years, indicating worsening dryness. The contribution of LST remained relatively stable, with a slight increase in negative impact in 2017 (-0.2111).

3.1 Correlation Analysis Between MRSEI and Indicators

Correlation analysis was performed to validate the representativeness of MRSEI. The results showed strong correlations between MRSEI and the four ecological indicators for all three periods (Table 2). In 1991, MRSEI exhibited correlation coefficients of 0.93, 0.94, -0.95, and -0.85 with NDVI, WET, NDSI, and LST, respectively. Similar patterns were observed in 2004 (0.96, 0.94, -0.93, -0.89) and 2017 (0.83, 0.86, -0.95, -0.81). The consistently high absolute correlation values (all above 0.80) demonstrate that MRSEI effectively captures the combined information from all four indicators.

The correlation between NDVI and WET was strong and positive across all years (0.82-0.85), indicating that vegetation growth is closely related to soil moisture. Both NDVI and WET showed strong negative correlations with NDSI (-0.85 to -0.87 and -0.82 to -0.87, respectively), confirming that higher vegetation cover and soil moisture correspond to lower surface dryness. The correlations between LST and the other indicators were also significant, with LST showing negative correlations with NDVI and WET, and positive correlation with NDSI.

3.2 Ecological Environment Evaluation

Based on the MRSEI values, the ecological environment of the Xilin Gol Steppe was classified into five levels: excellent, good, moderate, poor, and very poor. The area and proportion of each level were calculated for 1991, 2004, and 2017 (Table 3).

In 1991, the average MRSEI value was 0.41. Areas with excellent and good ecological status accounted for 35.40% and 53.21% of the total area, respectively, while moderate, poor, and very poor areas comprised 7.40%, 1.92%, and 2.07%. By 2004, the average MRSEI increased to 0.44, indicating overall improvement. The excellent and good areas expanded to 37.00% and 17.73% respectively, while moderate areas decreased significantly to 28.21%. However, by 2017, the average

MRSEI dropped to 0.27, showing substantial degradation. The excellent and good areas shrank dramatically to 20.93% and 25.00%, while poor and very poor areas expanded to 38.64% and 15.43%, respectively.

The spatial distribution patterns revealed that from 1991 to 2004, ecological improvement occurred primarily in the upstream region, while degradation was concentrated downstream. From 2004 to 2017, degradation accelerated across the entire basin, with only scattered patches of good environment remaining along the upper Xilin River banks and in the southern and southeastern parts of the drainage basin.

[Figure 1: see original paper]

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