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Grassland degradation and restoration monitoring and driving forces analysis based on long time-series remote sensing data in Xilin Gol League

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ABSTRACT

Land degradation is a process during which the land's productive capacity declines and eventually becomes completely lost under the influence of natural forces and human activities. With the development of remote sensing technology, long time-series of vegetation parameters has become available. In this study, time-series annual net primary production (NPP) datasets covering Xilin Gol League, Inner Mongolia, China during 2001 to 2012 were established based on an improved Carnegie-Ames-Stanford Approach (CASA) model. Then, the areas of grassland degradation and restoration were determined using the Sen + Mann-Kendall method. Finally, the driving forces of grassland degradation and restoration in this area were distinguished over the past 12 years through multiple and partial regression methods. The results showed the following five major findings: (1) From 2001 to 2012, areas showing degraded and restored trends were 2.36% and 9.37%, respectively, at the confidence level of $\alpha = 0.1$. There was a significant restored trend in Otindag sandy land and its surroundings, which indicates that some ecological engineering projects have achieved significant results. (2) Based on the combined analyses of multiple regression and partial regression, the main driver of grassland degradation in Xilin Gol League was identified as human activities, whereas climate change had a small influence. The effects of both human activities and climate change were the main drivers of grassland restoration; the single effect of human activities also played an important role in grassland restoration. (3) By comparing land use types in 2000 and 2010, we found that urban expansion and road construction occupied a major portion of grassland in Xilin Gol League in the past 10 years. Under the influence of the human activities, 3.2% of grassland experienced degradation and became bare land. In contrast, some areas showed vegetation recovery: 7.1% of bare land transformed to grassland. (4) By analyzing vegetation changes in the key nature reserves and coal mining areas, we found that vegetation in the earlier exploited mining areas was influenced seriously by human activities and showed a degradation trend; vegetation in the earlier protected nature reserve showed a restored trend under human activities. Simultaneously, in the new nature reserve, grassland productivity is improving. (5) The proposed methods of grassland degradation and restoration monitoring and driving force analysis were suitable for long time-series vegetation indicators datasets at the regional scale. These results may allow the local government to develop land degradation control strategies and provide a basis for using this improved method to study the influence of global climate change on land degradation.

At present, there is a general lack of a clear definition about land degradation [1]. Different scholars have different concepts of land degradation based on different focuses in researches [2–4]. Although emphasis varies among different definitions, the nature of land degradation, i.e. "the phenomenon that the potential biological productivity of an area has significantly declined due to the effect of natural or human factors", has been generally recognized [1]. Assessment and monitoring of regional land degradation/restoration has a vital significance in learning the distribution and degree of regional land degradation/restoration and understanding the dynamic trend of land degradation/restoration, thus allowing better scientific prevention and control.

Remote sensing technology has become the primary means of assessment and monitoring of land degradation/restoration in large scale and mainly focused on two methods. The first method combines visual interpretation with computer classification based on the instantaneous images obtained [5–8]. It is intended to assess land degradation by comparing classification results of remote sensing images in different periods and analyzing the transformation of land use types. Its biggest weakness lies in great influence of subjective views and inability to interpret the land degradation process. Meanwhile, it ignores the impacts of annual weather conditions on the absolute growth state of vegetation

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[9]. The second method is assessment and monitoring of land degradation/restoration based on the analysis of the variation trend of long time-series vegetation indexes. As a distinguishing feature of land degradation/restoration, vegetation degradation/restoration is typically reflected by decrease/increase of net primary productivity (NPP), vegetation coverage or biomass, and other vegetation indexes [10–12]. The advantages of this method include easy obtainment of assessment and monitoring data and suitability for the operations within a specified range. Therefore, the method of assessment and monitoring of land degradation/restoration by analyzing the variation trend of long time-series vegetation indexes has been successfully applied in recent years [13,14].

Since human activities and climate changes jointly affect vegetation dynamic changes, an in-depth analysis and understanding of the driving forces of land degradation/restoration has great significance in learning causes of land degradation/restoration and understanding the impact of global climate changes on the growth dynamics of vegetation. This will allow further implementation of scientific countermeasures and prevention and control strategies. Residual method is the most representative method for analyzing the driving forces of land degradation/restoration [15], the basic assumption of which is described below: In the remote sensing data of coarse resolution (kilo-class), the long time-series vegetation growth status in a unit pixel is mainly dependent on climatic factors, and human activities are less important. Therefore, the vegetation growth status under the independent effect of climate can be simulated based on the climate - vegetation statistical model [13,16–18] or the physical model [19–23]. Then, by comparing with actual growth status of vegetation, the extent of influence of human activities on the vegetation can be analyzed. To some extent, both methods simulate the vegetation growth status and have a certain application value. However, they have the following shortcomings: The modeling data based on the climate - vegetation statistical model has already contained certain influences of human activities. Therefore, the estimates of potential vegetation indexes cannot completely represent the vegetation growth status under independent climate effect. And as the models were built at different times and locations, there is a great dispute on the applicable scope of using the physical model to simulate the vegetation growth status under the independent effect of climate.

Studies based on the mathematical method analysis of the long time-series data can solve the aforesaid problem to some extent. But so far studies in this field have been rare. del Barrio et al. [24] distinguished the impacts of climate change and human activities on vegetation changes in Iberian Peninsula by combining multiple regression with relevant analysis and using the data of long time-series green vegetation fraction (GVF) as the basis. As the analysis of human activities or climate changes in the studied area adopted a correlation coefficient method, however, the climate factors are time-dependent, wrong judgments about impact of individual climate factors on degraded/restored lands may occur.

In view of this, in this study, NPP was selected as an indicator to assess the land degradation, and Xilin Gol League in Inner Mongolia was taken as a major study area. The grassland degradation/restoration in Xilin Gol League was determined by analyzing of the change trend of the long time-series NPP data during 2001 to 2012. And then, by adding the second variable to the significant change area for significance judgment of multiple regressions, the areas where human factors and climate factors jointly affect the degradation/restoration were determined. Finally, the areas influenced by human activities or climate change were determined through partial correlation analysis respectively. The results could provide basis scientific reference data for monitoring and study of grassland degradation/restoration driving mechanism in the study area.

1. Materials and methods

1.1. Study area

Xilin Gol League is located in the middle east of Inner Mongolia (as shown in Fig. 1), between 41°35′N–46°46′N and 111°09′E–119°58′E. Its southern part is predominated by low mountains and hills, with the terrain higher than its northern part. It covers a total area of 202,500 km^2, including 190,000 km^2 of grassland, accounting for about 95.03% of the total area. The study area is under a typical temperate continental semi-arid climate, which is cold in winter and hot in summer. The mean annual temperature is 1.3–4.8 °C. The annual precipitation is 150–400 mm, which decreases progressively from the east to the west. The rainfall is concentrated from June to August every year and the annual rainfall varies greatly [25]. As this area is in Beijing-Tianjin sand source region with a unique geographical location, it is important ecologically. Therefore, it has become an important area for the study on land degradation/restoration in recent years [26,27].

1.2. Data acquisition and processing

1.2.1. MODIS remote sensing data

The remote sensing data used in this study were MOD13Q1 NDVI product in 2001–2012 downloaded from https://ladsweb.nascom.nasa.gov. Its spatial resolution and time resolution were 250 m and 16 days respectively. Then, MRT tools was used for image mosaicking and projection transformation. The maximum value composite method was adopted to merge the 16-day data into monthly NDVI data for annual NPP estimation. In spite of these efforts, due to the impact of cloud pollution, snow coverage, data transmission error, and other adverse factors, there were still sudden changes in the monthly NDVI curves throughout a year [28]. Therefore, in this study, the method of S-G filtering [29] was applied to rebuild the monthly NDVI dataset, so as to eliminate the aforesaid adverse impacts.

1.2.2. Meteorological data

The meteorological data used in this study, such as temperature (T), precipitation (P), and ground downward shortwave radiation (S), were extracted from China Meteorological Forcing Dataset [30]. The time resolution of the original data of the dataset was 3 h and the spatial resolution was 0.1°. The integrated monthly data was used for NPP estimation.

1.2.3. Landuse type data

The landuse data adopted in this study was completed based on Landsat TM and HJ remote sensing images with a spatial resolution of 30 m. The data covered two years: 2000 and 2010. Data from 2000 was used for NPP estimation of 2001–2006, while data from 2010 was used for NPP estimation of 2007–2012. Taking into account the features of the landuse types in the study area and the accuracy of NPP estimation, in this study, the landuse types were divided into 8 types, namely forest land, shrub land, other forest land, grassland, water, urban and city, bare land, and farmland. Through type merging, re-sampling, projection transformation, and other operations, the data for these two years with the same spatial scale as NDVI was obtained. Fig. 2 gives the landuse classification data of 2010, which was mainly achieved with HJ data and object-oriented classification method. Its classification accuracy was up to 86% [31].

1.2.4. Measured NPP Data

The field measured NPP data was mainly applied to verify NPP estimation result. The research group carried out two field investigations in Xilin Gol League in August 2011 and August 2012 respectively. During the investigation month, the vegetation in the study area reached the maximum biomass. In the field investigation, other information regarding the sampling sites was also recorded, including vegetation fraction, main grass species, and height of dominant species, soil type, and sample site type, so as to provide reference for the analysis of results.

115 sampling sites were achieved in the study area during the two investigations (including 45 sites in 2011 and 70 sites in 2012), which were positioned with GPS (Trimble GeoExplorer 3000 Series), and the longitudes and latitudes of the central points of sampling sites were recorded. Above-ground biomass was measured by "harvest method"