ESTIMATION OF GRASSLAND DEGRADATION BASED ON HISTORICAL MAXIMUM GROWTH MODEL USING WITH REMOTE SENSING DATA

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ABSTRACT:

Grassland degradation is a complicated process and result of multi-system interaction. Observation on grassland vegetation growth and change is of critical importance to grassland resource management and environment construction. However, most of estimations on grassland degradation neglect sensitivity of grassland vegetation to annual climate change, and few of them considers the directive meaning of grassland degradation progress to the recovery of grassland environment. Therefore the results of different estimation methods are usually inconsistent and incomparable, which further leads to inconvenience in the implementation and supervision of grassland environment recovery. This paper proposed a new method to estimate grassland degradation based on discriminating the impact of climatic and non-climatic factors on vegetation. A historical maximum growth model is constructed to evaluate the "ideal" status of vegetation growth under fixed climatic conditions. The impact of non-climatic factors on vegetation could be measured by the difference between realistic and "ideal" status of vegetation growth. And then the change degree and direction of grassland degradation are estimated also. We applied the method in case study area of Xilin Gole Steppe in Inner Mongolia, China, by using Pathfinder NOAA/AVHRR NDVI data from 1983 to 2000 and the meteorological data within the same period. Comparing with results of others, this method is more accurate with respect to estimating spatial distribution and changing trend of grassland degradation. Moreover, it produces more consistent result comparing to the actual case.

1. INTRODUCTION

Grassland degradation has become a major environmental and economic problem in Inner Mongolia, china because it leads to desertification, reduces grassland productivity and biodiversity, and accelerates the occurrence of dust storms (Wu and Loucks, 1992; Liu and Wang, 1997; Wu and Overton, 2002). Xu, the Director-General for the Science and Technology Agency of Inner Mongolia Autonomous Region, expressed that desertification area in China has reached 27.3% of national land area, and it is increasing by 2460 km_2 per year: 400 million people are likely to be affected and the direct economic loss is estimated as 54 billion yuan per year.

Causes for grassland degradation have been asserted by many researchers, such as overgrazing by animals, incorrect agricultural management, collection of wood for fuel and herbs for medicine, and destruction by rodents. Many scientists admit that both nature and human factors are causes, but two contradicting arguments surround the main cause of desertification, with one citing natural origins such as climate change, and the other pointing to anthropogenic factors such as overgrazing (Nan, 2005; Yang et al., 2005). In fact, the most important thing is discriminating the natural and human-induced degradation for rehabilitation and reconstruction of degraded steppe regions, because human activities could be more easily to control than natural factors such as climate (Cao et al., 2006).

Evans and Geerken (2004) firstly presented a technique to discriminate between climate or human-induced dryland degradation, based on evaluations of AVHRR NDVI data and rainfall data. By performing many linear regression calculations between different periods of accumulated precipitation and the annual NDVImax, they identify the rainfall period that is best related to the NDVImax and by this the proportion of biomass triggered by rainfall. Positive or negative deviations in biomass from this relationship, expressed in the residuals, are interpreted as human-induced. Based on this method, the results of grassland degradation estimation in Syria are fit quite well into the overall picture of areas identified as overgrazed or degraded by the Syrian Ministry of Agriculture during extended field surveys. This method provided a very good way to solute the uncertainty of baseline assessment of degradation. But there is also a fatal shortcoming, as the evaluation criteria, the relationship of NDVImax and rainfall has included the impacts of human activities. In addition, temperature is also considered to have effects on grassland vegetation, which was neglected by this method (Yu et al., 2003).

The objective of this study is to establish a relatively ideal relationship model between grassland vegetation and climatic factors by minimizing the impacts of human-induced. Based on this model, the baseline of grassland degradation could be applied to any climatic conditions, and human-induced impacts on grassland vegetation could be evaluated easily.

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2. STUDY AREA AND DATA PRE-PROCESS

2.1 Study area and data collection

Xilingole is located in the middle part of the Inner Mongolia plateau in China. The landscape in Xilingole is a transition from meadow steppe to desert steppe. Typical steppe and desert steppe are the major types of community in this region.The dominant vegetation in a typical steppe are Stipa grandis, Leymus chinensis and S. krylovii etc. whereas for desert steppe they are S. klemenzii and S. gobica etc. (The comprehensive research team of Ningxia, Inner Mongolia, science academy of China, 1985). Precipitation mostly occurred in June, July and August; it also decreases from southeast to northwest (300–380mm). The annual mean temperature is between 0°C–3°C.

The NOAA/AVHRR-NDVI image used in this study was the ten-day data from Xilingole grassland during January 1983 to December 1999. The spatial resolution of the data is 8 km. These data were obtained from the Explorer Database of Earth Resources Observation System data center of the United States. The process included atmospheric correction, cloudy test and quality control and image matching, etc. (Townshend, 1994; James and Kalluri, 1994; Smith et al., 1997). Meteorological data, ten-day data series of mean temperature and precipitation during the corresponding time period from 54 meteorological stations of Inner Mongolia meteorological bureau were also collected. The study area and meteorological stations in the study are shown in Figure 1.

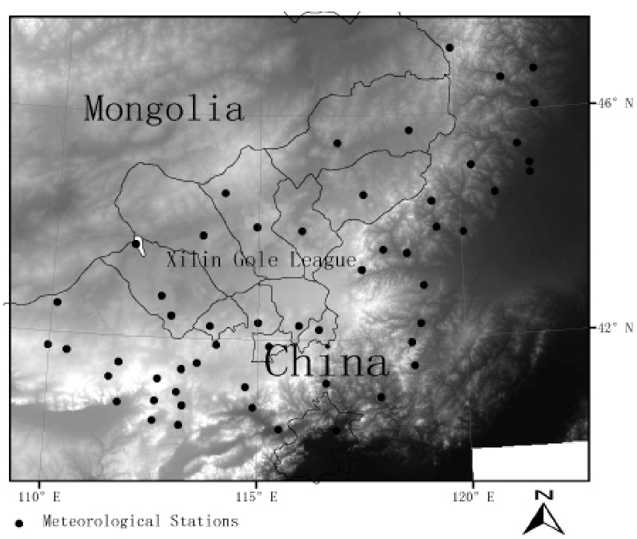

Figure 1 Study area and meteorological stations

2.2 Data pre-processing

Firstly, we interpolated climatic data from 54 meteorological stations into spatial surface of Xilin Gole League. Taking into account accuracy of interpolation, annual precipitation and ten-day temperature data were used.

Second, a method based on the Savitzky-Golay fliter to smooth data was applied on the NDVI time series data (Chen et al., 2004). This can help to reduce the noise caused by atmospheric condition change and air pollution.

To establish the relatively ideal relationship model of grassland vegetation and climatic factors, suitable vegetation parameters and corresponding climatic parameters must be selected. In this study, we selected annual precipitation and accumulated temperature as climatic factors. To reduce the impacts of factors such as satellite replacing, degradation of sensor capability, excursion of satellite orbit, etc, we selected NDVI-R as vegetation growth parameter using the following formula:

$$NDVI_R = NDVI_{\max} - NDVI_{onset} \tag{1}$$

Which: $NDVI_{max}$ = maximum of NDVI time series in each year

$NDVI_{onset}$ = NDVI value of vegetation growing season onset day when mean ten-day temperature was higher than 0°C

3. METHODOLGY

Our method is based on two assumptions: (1) that the NDVI data from a satellite sensor is primarily related to vegetation growth, such as, NDVI-R could represent the peak of vegetation growth; and (2) that non-climatic factors, such as insects, wild fire, grazing and human activities, all have negative effects on the growth of grassland vegetation. In line with these two assumptions, a new method based on the historical maximum NDVI-R data with certain climate condition was developed to reconstruct the best historical respond relations of vegetation and climate conditions. The historical maximum growth module was proposed to reproduce the "best" status of vegetation growth with minimum non-climate factors impact. Then the degradation of grassland caused by non-climate factors could be measured using deviation between actual and "best" status of vegetation growth. Accordingly, change trend of grassland degradation could be estimated based on this module. In the following, we first detailed descript the steps of constructing the historical maximum growth module, and then describe the estimation method of grassland degradation based on this module.

3.1 Historical Maximum Growth Module

As mentioned above, the historical maximum growth model of grassland vegetation production to climate is constructed based on long time series of remote sensing data and spatial interpolated meteorological data.

Firstly, we distributed all historical NDVI-R data to each type of grassland with different climate conditions. Such as for meadow steppe, we collected every NDVI-R data under different 10-mm intervals of 50-500mm annual precipitation condition. Accumulated temperature condition was correspondingly classified with 10℃ interval.

Secondly, the maximum NDVI-R data was selected from all historical data of each type of grassland under different annual precipitation or accumulated temperature condition. In order to avoid errors caused by satellite replacing or grassland types misjudgements, 10 percent of NDVI-R data higher than the others were collected and averaged for each grassland type by every year under with different climate conditions.

Third, we conducted the historical maximum growth model using NDVI-R data after processing and climate data. Analysis results of correlation and regression shown as following:

a) **Meadow Steppe:** different annual precipitation didn't have obviously effect on vegetations growth. However, accumulated temperature was higher, historical maximum NDVI-R would be lower.

b) **Typical Steppe:** precipitation and accumulated temperature both affected vegetations growth. With the increase of precipitation, vegetations of grassland produced more biomes, until over 450mm annual precipitation. Similarly, biomes of grassland would begin decreased when accumulated temperature does more than 220℃.

c) **Desert Steppe:** both precipitation and accumulated temperature had impacts on vegetation growth. The higher annual precipitation, vegetation growth better. However, similar to typical steppe, accumulated temperature has an impact of two-side on vegetation growth.

d) **Sandy Steppe:** similar to typical steppe, both precipitation and accumulated temperature had an impact of two-side on vegetation growth.

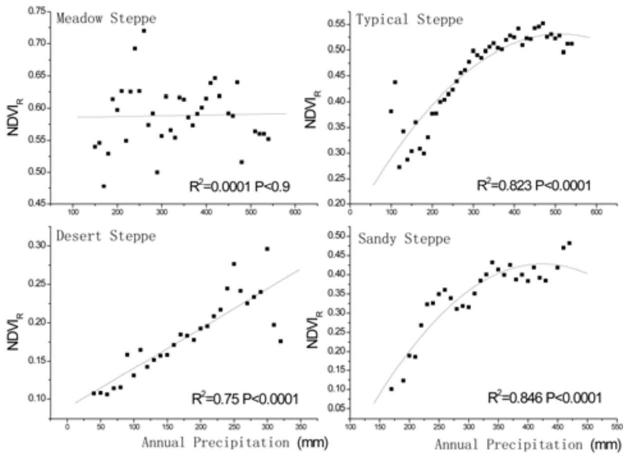

Figure 2 Regression analysis of historical maximum NDVI-R and annual precipitation for different type of grassland

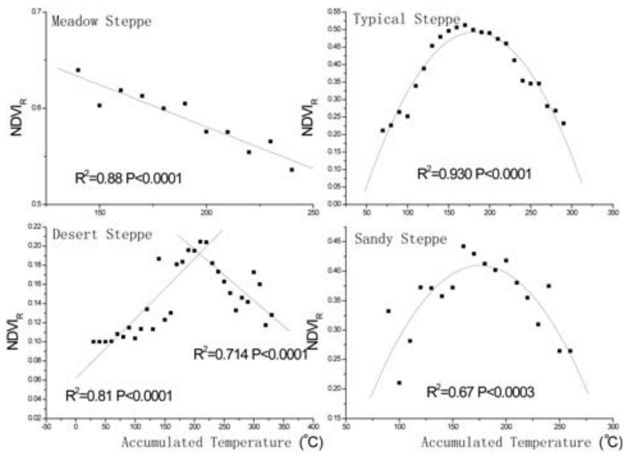

Figure 3 Regression analysis of historical maximum NDVI-R and accumulated temperature for different type of grassland

Finally, we could comprehensive different effects of precipitation and temperature on vegetation growth Historical maximum growth model for different type of grassland as fowling:

For Meadow Steppe:

$$NDVI_{Ri} = 0.75513 - 0.000871103 \times \mathrm{T} \tag{2}$$

For Typical Steppe:

$$NDVI_{Ri} = 0.15995 + 0.00145 \times P - 0.00000141631 \times P^2 \tag{3}$$

$$NDVI_{Ri} = -0.34808 + 0.00926 \times T - 0.0000254488 \times T^2 \tag{4}$$

For Desert Steppe:

$$NDVI_{Ri} = 0.08848 + 0.000519047 \times P \tag{5}$$

$$NDVI_{Ri} = 0.06156 + 0.000625839 \times T \qquad (T \le 220°C) \tag{6}$$

$$NDVI_{Ri} = 0.30286 - 0.000532547 \times T \qquad (T \succ 220°C) \tag{7}$$

For Sandy Steppe:

$$NDVI_{Ri} = -0.38457 + 0.00383 \times P - 0.00000451437 \times P^2 \tag{8}$$

$$NDVI_{Ri} = -0.2463 + 0.00747 \times T - 0.0000212569 \times T^2 \tag{9}$$

Where: $NDVI_{Ri}$ = ideal status of vegetation growth with certain annual precipitation of accumulated temperature
P = annual precipitation
T = accumulated temperature

3.2 Estimation of Grassland Degradation

The complexity of different effects of precipitation and temperature on each type of grassland were taking into account, we simplified our historical maximum growth model. In a certain climatic conditions of precipitation and temperature combinations, the lower one derived from historical maximum growth model represents the ideal status of vegetation growth. Using following formula (9), we could obtain all deviations of vegetation actual growth from ideal status based on the simplified model.

$$\sigma = \left(NDVI_{Ra} - NDVI_{Ri}\right) / NDVI_{Ri} \tag{10}$$

Where: σ = deviation of vegetation actual growth from ideal status
$NDVI_{Ra}$ = actual status of vegetation growth with certain climatic conditions
$NDVI_{Ri}$ = ideal status of vegetation growth with certain climatic conditions

Grassland degradations were measured from tow aspects: (1) average deviations of vegetation actual growth from ideal status from 1982 to 2000, which represent the severity of grassland degradation in different region; (2) change trends of deviations from 1982 to 2000, which demonstrate the area with increasing influence of non-climatic factors.

Referring to natural grassland degradation local standard of Inner Mongolia Autonomous Region, we defined three levels of degradation: normal with > -0.1 deviations; mild degraded with -0.4 - -0.1 deviations; moderately degraded with -0.7 – 0.4 deviations; heavily degraded with < -0.7 deviations.

4. RESULTS AND DISCUSSION

4.1 Results

Estimations of grassland degradation in Xilin Gole League from 1982 to 2000 from two aspects are shown in figure 4. The results found 70-90% of grassland degradation occurred over the years, among this, about 48% mild degraded; about 31% moderately degraded; about 3% heavily degraded. From the long-term trend of deviations, area of grassland degradations caused by non-climatic factors was decreasing, at the same time extent of degradation was reduced.

Spatial distribution of average deviations of vegetation actual growth from ideal status showed the most serious grassland degradation occurred in XiangHuang, south of Sonid Right and east of Sonid Left; secondly in west of Abaga and south of Zhengxiangbai, lesser in East Ujimqin and West Ujimqin. On the contrary, the long term change trend of deviations showed increasing effects of non-climatic factors in East Ujimqin and West Ujimqin; decreasing effects in Xianghuang, Abaga, Zhengxiangbai and Taibus.

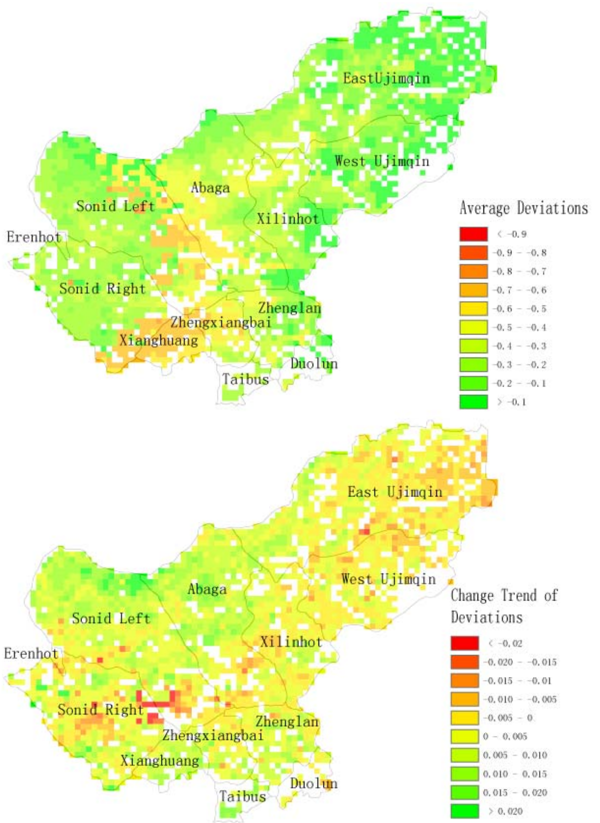

Figure 4 estimation of grassland degradation in Xilin Gole League from 1982 to 2000 (Up: average deviations of vegetation actual growth from ideal status from 1982 to 2000; Down: change trend of deviations from 1982 to 2000)

4.2 Discussion

The results showed that effects of non-climatic factors on grassland vegetation were decreasing in most of Xilin Gole grassland. It's not unanimous in results of other researches because of different evaluation criteria. However, comparing with results of grassland degradation estimation of Xianghuang (Dong Yongping, 2004), spatial distribution of degradation extent are basically the same.

According to a survey, although the contracts of livestock and grassland were carried out in Xilin Gole League from 1985, grassland wasn't contracted to herder households until 1997-1999 in fact. During this period, grassland survived the destruction and plundering caused by unreasonable grazing behavior. This shows that extent of grassland degradation in Xilin Gole League in the later 1980s was higher than in the later 1990s, which is consist with our estimation of grassland degradation trend in Xilin Gole League.

5. CONCLUSSION

Most of estimations of grassland degradation are based on comparison of two absolute statuses, which neglected effects of climate on vegetation growth status. This paper presents the historical maximum growth model based on minimized effects of non-climatic factors on vegetation growth. As the baseline of grassland degradation estimation, we could accurately descript the extents of grassland degradation under the same climate conditions or non-climatic factors pressures.

Through selecting the historical maximum NDVI-R value of vegetation growth under different climatic conditions, effects of non-climatic factors were minimized. The historical maximum growth model showed significant correlations between vegetation growth and climatic factors, which are consistent with ground survey of grassland in Xilin Gole League (Wang Yuhui, 2002).

The results of grassland degradation estimations showed that effects of non-climatic factors on grassland vegetation were decreasing in most of Xilin Gole grassland. Comparing with results of other researches, this study seemed more in line with reality of Xilin Gole League.

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