LAND DEGRADATION ASSESSMENT BY APPLYING RELATIVE RUE IN INNER MONGOLIA, CHINA, 2001-2010
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ABSTRACT
Land degradation in Inner Mongolia, China is much severe. Remote sensing application on land degradation assessment can provide scientific basis for land degradation prevention in the study area. In this paper, land degradation was assessed by applying two improved relative Rain Use Efficiency (RUE) indicators based on time series MODIS NDVI data and high-resolution meteorological data from 2001 to 2010. The results show that 76.74% land of the whole study area with good or unusually good condition, it indicates that the most areas have normal or good vegetation production capacity. The unusually degraded and degraded lands account for 11.94% of the study area, especially they are less degraded lands distributing in Beijing and Tianjin sandstorm source region within the Inner Mongolia, it indicates that some ecological engineering projects implemented in this area have achieved significantly for restoration of degraded ecosystems in recent 10 years.

Index Terms—Geoscience and remote sensing, relative Rain Use Efficiency, land degradation, Inner Mongolia

1. INTRODUCTION
Land degradation is a process that land productive capacity continues to decline or even lose completely under the influence of natural forces and human activities. The land degradation in China is severe[1-2], especially in Northern part of China, by which the safety of grain production has been affected greatly[3].

The net primary production (NPP), which can be estimated using remotely sensed data[4-5], is a key indicator for land degradation assessment [6], but many studies have shown that NPP and precipitation have a high correlation in the drylands[7-8]. The NPP will be higher when there is more precipitation in some year, otherwise the NPP will be lower. Therefore, some studies found that the Rain Use Efficiency (RUE) may be a more efficient indicator for land degradation assessment, because it can eliminate the effects of precipitation change on NPP[9-11]. On the basis of RUE, Gabriel et al. further proposed the relative RUE (rRUE) could be a better indicator than RUE indicating land degradation, and found that it may resolve the problem that the RUE can't be compared among different climatic zones[12].

In this study, land degradation was assessed by applying two improved rRUE indicators in Inner Mongolia of China during the recent 10 years, where the land degradation is prevailing in China. It was expected that can promote the development of remote sensing application on land degradation assessment, and provide scientific basis for land degradation prevention in the study area.

2. MATERIALS AND METHODS
The Inner Mongolia Autonomous Region, bordering with Mongolia and Russia in the north, is one of largest provincial region in China. The climate ranges from arid, semi-arid and humid from west to east. The main land cover types include forest, rangeland and desert. The land degradation is much severe, resulting from land sandification, water and soil erosion, soil salinization etc. Fig. 1 shows the location of the study area.

Fig.1 Location of study area
Annual NPP was estimated based on the monthly MODIS NDVI and a high-resolution meteorological raster dataset of China during 2001-2010, with 250 m×250 m and 0.1°×0.1° resolution respectively[13]. The meteorological data was also used to estimate the Climatic Moisture index (MI) using Thornthwaite method in study area[14]. The land cover data (2000) was acquired from website of the Environmental & Ecological Science Data Center for West China (http://westdc.westgis.ac.cn), which was used in estimation of NPP and rRUE. The annual pixel-based NPP derived from MODIS NDVI was calculated based on the improved Carnegie-Ames-Stanford Approach model(CASA)[15], RUE was defined as the ratio of NPP to precipitation over a given time period.

The rRUE_ex and rRUE_me were used for land degradation assessment in this study. The rRUE_me can reflect the restoring elasticity of different ecosystems. The formulas for calculation are as follows:

\[
rRUE_{ex} = \frac{RUE_{ex} - RUE_{ex/min}}{RUE_{ex/max} - RUE_{ex/min}}
\]

(1)

\[
rRUE_{me} = \frac{RUE_{me} - RUE_{me/min}}{RUE_{me/max} - RUE_{me/min}}
\]

(2)

RUE_me is the pixel-based mean of annual RUE, while RUE_ex is the pixel-based maximum annual RUE during 2001-2010. The RUE_me/max, RUE_me/min and RUE_ex/max, RUE_ex/min are the pixel-based maximum and minimum RUE values determined by the upper and lower boundary functions of RUE_me and RUE_ex respectively. The upper and lower boundary functions were created between RUE_me/RUE_ex and each MI classes, and the sum of standard deviation and mean was taken as the upper boundary while the difference between mean and standard deviation was set as the lower boundary.

<table>
<thead>
<tr>
<th>rRUE_me &lt; 0</th>
<th>0≤rRUE_me≤1</th>
<th>1&lt;rRUE_me</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unus. Degr.</td>
<td>Degr.</td>
<td>Anomaly</td>
</tr>
<tr>
<td>0≤rRUE_ex≤1</td>
<td>Good</td>
<td>Unus. Good</td>
</tr>
<tr>
<td>1&lt;rRUE_ex</td>
<td>Anomaly</td>
<td>Unus. Good</td>
</tr>
</tbody>
</table>

3. RESULTS AND ANALYSIS

According to the climate characteristics of the study area, MI was divided into 30 classes by set 0.04 as the classification interval. Follow the method that mentioned above, the pixel-based mean of annual RUE (RUE_me) and pixel-based maximum annual RUE (RUE_ex) were calculated in the study area during 2001-2010. Then, under the scatterplots distribution of RUE_me and RUE_ex(Fig.3), the upper and lower boundary functions of RUE_me and RUE_ex were established(Tab.2). Finally the rRUE_ex and rRUE_me in recent 10 years were calculated by Eq. (1) and (2).

Scatterplots and boundary functions of observed RUE over study area show that, the increase in observed RUE_me becomes gentler with increasing MI. In our study, when MI reached 0.9, the RUE_me highest. The annual precipitation in the arid land is relatively less, so that the invalid proportion of water for vegetation growth is less, and the annual precipitation will be used entirely. But in the humid region, precipitation is no longer a major factor to limit the growth of vegetation, so the increasing trend turns smooth.

Tab.1 Land degradation classes

Fig. 3 Scatterplots of RUE_me and RUE_ex with MI

Tab.2 Models of the boundary functions
The Spatial distribution of \( r_{\text{RUE}_{\text{me}}} \) and \( r_{\text{RUE}_{\text{ex}}} \) were shown in Fig. 4. The results indicated that both \( r_{\text{RUE}_{\text{me}}} \) and \( r_{\text{RUE}_{\text{ex}}} \) in southwest ecotone is significantly lower than that in other parts in recent 10 years. The higher \( r_{\text{RUE}_{\text{me}}} \) and \( r_{\text{RUE}_{\text{ex}}} \) values mainly appeared in typical rangeland and forest areas in the east and northeast of the study area. By contrast, the lower values mainly appeared in Middle West mainly covered by the Mu Us Sandy lands, Badan Jaran desert and Tengger Desert. It is worth noting the values of two indicators were also higher in the driest western area.

The Spatial distribution of \( r_{\text{RUE}_{\text{me}}} \) and \( r_{\text{RUE}_{\text{ex}}} \) values in the Inner Mongolia, China (2001-2010)

The results of land degradation assessment in the study area by applying \( r_{\text{RUE}_{\text{me}}} \) and \( r_{\text{RUE}_{\text{ex}}} \) were shown in Tab. 3 and Fig. 5. The farmlands and cities as artificial ecosystems were excluded in assessment. The lands with good or unusually good condition approximately account for 76.74\% of the whole study area, which indicates that the most areas have normal or good vegetation production capacity. The unusually degraded and degraded lands account for 11.94\% of the study area, which mainly appeared in southwest ecotone regions, where most are covered by the Mu Us sandy lands, Loess Plateau and south hilly areas. There are less degraded lands distributing in Beijing and Tianjin sandstorm source region within the Inner Mongolia, including the Otindag sandy lands and Horqin sandy lands, which indicates that some ecological engineering projects implemented in this area have achieved significantly for restoration of degraded ecosystems in recent 10 years[16].

**Tab. 3** Statistics of land degradation classes in the study area from 2001-2010(%)  

<table>
<thead>
<tr>
<th>Land Production Capacity</th>
<th>Total Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unus. Degr.</td>
<td>8.21</td>
</tr>
<tr>
<td>Degr.</td>
<td>3.73</td>
</tr>
<tr>
<td>Good</td>
<td>62.80</td>
</tr>
<tr>
<td>Unus. Good</td>
<td>13.94</td>
</tr>
<tr>
<td>Anomaly</td>
<td>0.01</td>
</tr>
<tr>
<td>Others*</td>
<td>11.32</td>
</tr>
</tbody>
</table>

*It contains 0.1\% cities and towns, 1.29\% water and 9.93\% farmland.

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5. REFERENCES


