Assessment of land degradation using time series trend analysis of vegetation indicators in Otindag Sandy land

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Abstract. Land condition assessment is a basic prerequisite for finding the degradation of a territory, which might lead to desertification under climatic and human pressures. The temporal change in vegetation productivity is a key indicator of land degradation. In this paper, taking the Otindag Sandy Land as a case, the mean normalized difference vegetation index (NDVI_a), net primary production (NPP) and vegetation rain use efficiency (RUE) dynamic trends during 2001-2010 were analysed. The Mann-Kendall test and the Correlation Analysis method were used and their sensitivities to land degradation were evaluated. The results showed that the three vegetation indicators (NDVI_a, NPP and RUE) showed a downward trend with the two methods in the past 10 years and the land was degraded. For the analysis of the three vegetation indicators (NDVI_a, NPP and RUE), it indicated a decreasing trend in 62.57%, 74.16% and 88.56% of the study area according to the Mann-Kendall test and in 57.85%, 68.38% and 85.29% according to the correlation analysis method. However, the change trends were not significant, the significant trends at the 95% confidence level only accounted for a small proportion. Analysis of NDVI_a, NPP and RUE series showed a significant decreasing trend in 9.21%, 4.81% and 6.51% with the Mann-Kendall test. The NPP change trends showed obvious positive link with the precipitation in the study area. While the effect of the inter-annual variation of the precipitation for RUE was small, the vegetation RUE can provide valuable insights into the status of land condition and had best sensitivity to land degradation.

1. Introduction

According to the definition of the United Nations Convention to Combat Desertification (UNCCD), ‘desertification’ means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variations and human activities [1]. Desertification or land degradation has become one of the world's most serious environmental and socio-economic problems [2]. China is one of the major countries facing this problem. The total area of desertification-prone land has been reported as approximately 2.62 million km², occupying 27.3% of the total area of China [3]. Scientists around the world started long ago to look at the problem and have shown vegetation as a good indicator of land degradation assessment in many countries. Land degradation is often linked to a decline in biomass or vegetation cover, which may be measured in terms of biomass productivity or undesirable changes in composition [4-6]. Many vegetation indicators include vegetation cover, vegetation indices, biomass and leaf-area index were analyzed for land degradation in global, national,
local and field/farm levels, however significantly, vegetation indicators need to be critically selected, taking into account their suitability, applicability and adaptability to local conditions.

Satellite remote sensing has long been considered an ideal technology for monitoring vegetation dynamics because it permits the analysis of large areas with a high temporal frequency [7-10]. With new sensors such as MODIS (MODerate resolution Imaging Spectroradiometer), new data are available to extract key phenological parameters and monitor dynamic trends in vegetation. A vegetation index (VI) is a quantitative value measuring vegetation conditions and is often obtained through the combination of different types of spectral or remote sensing data. Many studies have used vegetation indices calculated to monitor trends in primary productivity for the purposes of assessing land degradation [11-17]. Vegetation indices (VIs), especially NDVI, have been widely used as a parameter of vegetation dynamics in the above research. Because the net primary productivity (NPP) calculation is very complex, many scholars have used a consistent and reliable time-series archive as a proxy for NPP to assess land degradation. However, few studies have calculated NPP and analyzed dynamic change trends for the assessment of land degradation. Many studies [18-19] have shown that NPP and precipitation (P) have a high correlation in the arid and semi-arid regions of China. The NPP will be higher in a year that has more rainfall. When the precipitation is less in the year, the NPP will be lower. Therefore, the vegetation rain use efficiency (RUE), which is the ratio of NPP to P, was also used to analyze the vegetation trends and assess the land degradation.

The Otindag Sandy Land, located in the north of China, has been seriously affected by desertification and has suffered from severe wind erosion and a high frequency of dust storms. Thus, it is very important to determine the vegetation change trends to assess land degradation in this area. Taking the Otindag Sandy Land as a case study area, land degradation and vegetation dynamic trends during 2001-2010 were analyzed using NDVI, NPP and RUE data with the correlation analysis method and the Mann-Kendall statistical test.

2. Materials and methods

2.1. Study area
The Otindag Sandy land is located in the south eastern part of Inner Mongolia, which is about 340 km long from east to west and 30-100 km in width (from 42° 10′ N and 112° 10′ E to 43° 50′ N and 116° 30′ E). The elevation varies between 1100m and 1400m and the topography declines from southeast to northwest. The climate is temperate continental semi-arid type with strong wind and less precipitation in winter and in spring. Annual average precipitation, mainly occurring in summer and fall with some inter-annual fluctuation, is nearly 400mm in the south eastern part and below 200 mm in the northwest. The typical grassland vegetation consists of perennial herbs, such as Leymus chinensis, Stipa grandis, Leymus secalinus, Agropyron cristatum, Koeleria cristata, Psammochloa villos and Agropyron mongolicum etc. Because of sandy substrate, the Otindag Sandy Land possesses a high biodiversity and spatial heterogeneity. The dominant communities in Otindag Sandy Lands consist of Caragana Microphylla, Ulnus pumila and Artemisia sp.

2.2. Dataset
Monthly MODIS normalized difference vegetation index (NDVI) data at a resolution of 250×250 m for 2001-2010 were used in the research. The meteorological raster data used include rainfall, temperature and solar radiation at a resolution of 0.1×0.1° for the same period [20]. The meteorological data had the same spatial resolution as the MODIS NDVI after resampling. Land-cover (2000) data were downloaded from the “Environmental & Ecological Science Data Center for West China, National Natural Science Foundation of China” (http://westdc.westgis.ac.cn).
2.3. Methods

2.3.1. Data preprocessing. Mean NDVI (NDVI\textsubscript{a}) is defined as the average NDVI for each monthly NDVI in a year. The improved Carnegie-Ames-Stanford Approach (CASA) model [21] was applied to calculate NPP. The CASA model which was run with the NDVI data, climate data and vegetation type has been widely used to obtain NPP in China. In this study, we chose the same parameter as Zhu used [21]. The annual NPP was generated by the average of NPP for each monthly in a year. The RUE was the ratio of the annual NPP to the annual precipitation.

2.3.2. Methods for trend analysis. The Correlation Analysis method and the Mann-Kendall statistical test were used in this research. Pearson's correlation coefficient \(r_{xy}\) was calculated in our work. An \(r_{xy}\) greater than zero indicates a positive correlation and increasing trends. An \(r_{xy}\) less than zero indicates a negative correlation and decreasing trends. At a chosen level of significance, \(\alpha=0.05\), if \(|r_{xy}|>0.6319\), then the trend of the series is significant. The Mann-Kendall statistical test is a non-parametric test that does not require the data to be distributed normally. The MK test has been widely used because it is simple and can cope with missing data. The test statistic, Kendall’s s and the standardized test statistic Z are calculated [22-23]. Positive values of Z indicate increasing trends, while negative values of Z show decreasing trends. When testing either increasing or decreasing monotonic trends at the \(\alpha\) significance level, the null hypothesis is rejected for an absolute value of Z greater than \(Z_{1-\alpha/2}\), obtained from the standard normal cumulative distribution tables [24-25]. In this research, significance levels of \(\alpha=0.05\) were applied.

3. Results

Both the Correlation Analysis Method (CAM) and the Mann-Kendall test (MK) of NDVI\textsubscript{a}, NPP and RUE were performed for each cell in the study area to determine their change trends. The results of the CAM and MK test for the three vegetation indicators are given in Table 1. The trends found by the CAM were mostly similar to each vegetation indicator NDVI\textsubscript{a}, NPP or RUE trend found by the MK test. However, there was slight difference among the three vegetation variables within each method. Decreasing trends in NDVI\textsubscript{a} were observed in 57.85% of the total area with the CAM and in 62.57% of the study area with the MK test. The decreasing trends were significant at the 95% confidence level with the parametric method (CAM) and the non-parametric method (MK test) in 10.63% and 9.21% of the total area, respectively. The significant increasing trends for the NDVI\textsubscript{a} found by the MK test and the CAM were found in 1.97% and 2.06% of the study area.

For the NPP and RUE, 74.16% and 88.56% of the study area showed a downward trend according to the MK test, and 68.38% and 85.29% of the total area showed a downward trend combined with the CAM. The trends were significant at the 95% confidence level with the MK test in 5.50% and 6.62%
of the total area; significant decreasing trends accounted for 4.81% and 6.51% while significant increasing trends accounted for 0.69% and 0.11%. In addition, the trends were significant at the 95% confidence level with the parametric method (CAM) in 5.22% and 7.05% of the total area. Approximately 4.45% and 6.92% of the total area was associated with a significant downward trend, and significant upward trends accounted for 0.77% and 0.13% of the study area.

The MK test and the CAM for the three vegetation indicators NDVI_a, NPP and RUE showed that there was a decreasing trend in the vegetation productivity in the past ten years. The results illustrate the land productivity had a downward trend. However, the downward trend was not significant, the significant trends at the 95% confidence level accounted for only a small proportion.

**Table 1.** The percentage of total area with significant trends according to the MK test and the CAM for NDVI_a, NPP and RUE.

| Methods | Trends                      | NDVI_a | NPP    | RUE  |
|---------|-----------------------------|--------|--------|------|
| CAM     | Significant decrease        | 10.63% | 4.45%  | 6.92%|
|         | Decrease, but not significant | 47.22% | 63.93% | 78.37%|
|         | Increase, but not significant | 40.09% | 30.85% | 14.58%|
|         | Significant increase        | 2.06%  | 0.77%  | 0.13%|
| MK      | Significant decrease        | 9.21%  | 4.81%  | 6.51%|
|         | Decrease, but not significant | 53.36% | 69.35% | 82.05%|
|         | Increase, but not significant | 35.46% | 25.15% | 11.33%|
|         | Significant increase        | 1.97%  | 0.69%  | 0.11%|

**Figure 2.** Spatial patterns of the MK test of three vegetation indicators during 2001-2010: (a) - NDVI_a; (b) -NPP; (c) - RUE.

The spatial distributions of the trends according to the MK test in the three vegetation indicators NDVI_a, NPP and RUE for the study period (2001-2010) are shown in Fig. 2, respectively. It is noted
that all trends detected are significant at the 0.05 level. The regions located in the northeast (marked as red in Figs. 2a and 2b) completely display negative trends, suggesting a significant decrease in NDVI_a and NPP. Similar findings appear in mid-southern region. The region located in the northwest (Figs. 2a and 2b) displays positive trends. Furthermore, a small region situated mostly to the northwest and southeast (marked as dark green in Fig. 2a) display significant increase trends, suggesting a significant increase in NDVI_a over the past ten years. The spatial distribution of trends with the MK test in NDVI_a and NPP were mostly similar, however, that was very different in RUE and NPP. The spatial distribution of the significant downward trends with the MK for RUE was scattered. Furthermore, the increase trends, occupying a small proportion, the spatial distribution were also scattered.

4. Discussion and conclusions

Previous studies [18-19] have shown that vegetation activity and precipitation have high correlations in the arid and semi-arid regions. The NDVI and NPP will be higher in a year that has more rainfall. When the precipitation is less in the year, the NDVI and NPP of the vegetation is lower. The interannual variations of precipitation and NDVI_a and NPP were analyzed in the Otindag Sandy Land during 2001-2010 (Fig. 3). The interannual variation of precipitation was parallel with that of NDVI_a and NPP. In 2003, 2004 and 2006, the NDVI_a and NPP was relatively high, coinciding with peaks of precipitation. Similarly, the NDVI minima of 2001 and 2005 correspond with the minima of the precipitation over these years. Hence, the precipitation is the dominated force for the NDVI_a and NPP change in the Otindag Sandy Land. Our finding is consistent with many previous studies, which have indicated that vegetation growth in arid and semi-arid regions is very sensitive to precipitation changes [26-27].

![Figure 3. Interannual variations of precipitation and NDVI_a and NPP in the Otindag Sandy Land during 2001-2010.](image_url)

The trends of the NDVI_a, NPP and RUE time series were analyzed using CAM and MK test in the Otindag Sandy Land during 2001-2010. The results show that the three vegetation indicators (NDVI_a, NPP and RUE) presented a downward trend in the past 10 years and that the land was degrading. For the NDVI_a, NPP and RUE, there was a decreasing trend in 57.85%, 68.38% and 85.29% of the study area with the correlation analysis method and in 62.57%, 74.16% and 88.56% of the study area with the Mann-Kendall test. However, the decreasing trends of NDVI_a, NPP and RUE were significant at the 95% confidence level in 9.21%, 4.81% and 6.51% (MK test) of the study area, respectively.

This paper also indicates that the NDVI_a and NPP change trends showed an obvious positive link with precipitation in the study area, while the effect of the inter-annual variation of precipitation for RUE was small. The vegetation rain use efficiency may provide valuable insight into the status of the land condition.
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