

Changing Landscapes: Monitoring Ecologically Sensitive Ecosystems in a Dynamic Semi-Arid Landscape Using Satellite Imagery: A Case Study in Ejin Oasis, Western China

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ABSTRACT

Land degradation has become an important issue in western China recently. Oasis ecosystem is sensitive to environmental disturbances, such as abnormal /extreme events of precipitations, water supply from upper watersheds, fluctuations of temperatures, etc. Satellite remote sensing of terrestrial ecosystems provides temporal dynamics and spatial distributions of landscape green covers over large areas. Seasonal green cover data are normally important in assessing landscape health (ex. desertification, rate of urban sprawl, natural disturbances) in arid and semi-arid regions. In this study, green cover data is derived from vegetation indices retrieved from MODIS sensors onboard Terra. The satellite images during the period April 2000 to December 2005 are analyzed to quantify the spatial distribution and temporal changes of Ejin Oasis. The results will help improving monitoring techniques to evaluate land degradation and to estimate the newest tendency of landscape green cover dynamics in the Ejin Oasis.

Keywords: land degradation, monitoring, green cover, landscape, oasis

1. INTRODUCTION

The study of monitoring vegetation is an important part of applications of remote sensing data. This information is crucial for understanding processes such as carbon cycling, terrestrial primary productivity, hydrologic cycles, and terrestrial energy balance. Remote sensing methods have been applied over a number of regions worldwide to monitor vegetation changes¹⁻⁹. A large number of these works show that remote sensing has been considered to be a useful method for studying arid and semi-arid ecosystems^{1, 5, 8-13}. For example, time-series analyses of satellite data enable observations of seasonal, annual and inter-annual trends in vegetation cover. NOAA-AVHRR images have been utilized

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to generate a 23-year time series for long-term studies of Sahel region to assess inter-annual trend⁹. They found that this time series reveals two periods; (a) 1982–1993 marked by below average NDVI and persistence of drought with a signature large-scale drought during the 1982–1985 period; and (b) 1994–2003, marked by a trend towards 'wetter' conditions with region-wide above normal NDVI conditions with maxima in 1994 and 1999. Thus, it is useful to use satellite imagery to monitor large regions in vegetation and land surface dynamics because of data availability for long term periods.

Recently, Moderate resolution imaging Spectroradiometer (MODIS) is providing information from 250m to 1Km spatial level. The MODIS was recently launched onboard the Earth Observing System (EOS) Terra/Aqua platform and provides a suite of vegetation products useful for terrestrial ecosystem studies¹⁵⁻¹⁷. One attractive advantage of MODIS is that it provides images of the entire globe every 1 or 2 days. Two MODIS vegetation indices, the normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI), are produced at 250m, 500m, and 1 km resolutions with 16-day compositing periods and are designed for landcover change, ecological processes, and seasonal and inter-annual monitoring of vegetation. The use of MODIS sensor time-series data has significant potential to enhance environmental studies over regional scales.

The term landscape has been widely used in many fields, including landscape ecology, geography, geomorphology, landscape architecture, land use, and environmental studies. Forman defined landscape as “a mosaic of where the mix of local ecosystems or land uses is repeated in similar form over a kilometer-wide area”¹⁸. Thus any landscape will almost contain a number of ecosystems as well as a mosaic of different kinds of vegetation. Landscape sensitivity as a concept comes from geomorphology and means the likelihood of change, i.e. of instability and stability¹⁹. One major problem is that landscape sensitivity varies spatially as a result of inherent landscape patterns (such as rocks, soils, altitude, slopes, plant cover). Therefore, the vegetation index, NDVI, is used to assess and monitoring the integrated characteristics of complicated ecological functions on the land surface.

The objective of this study is to better understand landscape dynamics in arid and semi-arid environments. Therefore, remotely sensed data were utilized to characterize landscape seasonality in Ejin oasis, which located in western China with an arid and semi-arid environment. We also explored seasonal variations of sensitive ecosystems in a landscape for discussing concepts of landscape sensitivity. In this study, we interpreted seasonal green cover maps of Ejin oasis to monitor vegetation dynamics. A comparison of seasonal dynamics for the winter, spring, summer, and fall's spatial extents and distributions of vegetation area was made with NDVI images. The landcover maps in summer season were classified by satellite images to compare the landcover dynamics in 2000 and 2005. Finally, the landscape sensitivity analysis was developed to assess the sensitivity of ecosystems in the landscape of Ejin.

2. METHODOLOGY

2.1 Remote sensing approach

The method proposed in this study included six processing steps: 1) image processing, including mosaicing, subsetting, and reprojecting, 2) cloud mask generation of time series data sets, 3) NDVI image generation of time-series data sets, 4) land cover interpretation for summer image during the period from 2000 to 2005, 4) seasonal NDVI variation analysis, 5) landscape sensitivity analysis.

Time-series bi-weekly remotely sensed images from the year February 2000 to December 2005 were analyzed for the region of Ejin Oasis. All the MODIS bi-weekly composite images used in this study have a spatial resolution of 250m. The bi-weekly image composition algorithm relies on multiple observations over a 16-day period and operates on a per-pixel basis to generate the images. They involve transformations of the red (620-670 nm), near-infrared (841-876 nm), and blue (459-479nm) bands designed to analyze the vegetation activities and allow for comparisons of spatial and temporal variations in terrestrial ecosystems.

The NDVI is an important parameter to various kinds of local, regional, and global scale models, including general circulation and biogeochemical models²⁰. They serve as intermediaries in the assessment of various biophysical parameters, such as green cover, biomass, LAI, and fraction of absorbed photosynthetically active radiation (fAPAR)(Tucker, 1979; Sellers et al., 1992). Therefore, the NDVI has been played a significant role in monitoring regional and global photo synthetically active biomass processes.

The NDVI utilizes differences in leaf absorptions in the red and near-infrared bands²¹⁻²², which is a measure by dividing the difference in infrared and red reflectance measurements. It is formulated as follows:

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \quad (1)$$

where ρ_{NIR} and ρ_{red} are the surface reflectances in the 620-670 nm (visible) and 841-876 nm (infrared) regions of the electromagnetic spectrum, respectively.

2.2 Landscape Sensitivity Analysis

In this study, we used NDVI to diagnose landscape sensitivity. Seasonal variations in landscape dynamics were compared with the NDVI responses of winter, spring, summer, and fall season. The assessments of landscape sensitivity were used both absolute and relative measures of percent variations. The equations used to depict seasonal variation were modified from^{6, 26}:

$$\text{Relative Seasonal Variation} = \left| \frac{\text{Seasonal NDVI}_{(i)} - \text{Seasonal NDVI}_{(j)}}{\text{Seasonal NDVI}_{(j)}} \right| * 100\% \dots\dots\dots(2)$$

where i is the season latter than j, such as i is summer and j is spring.

$$\text{Landscape sensitivity (LS)} = (\text{RSV}_{\text{winter}} + \text{RSV}_{\text{spring}} + \text{RSV}_{\text{summer}} + \text{RSV}_{\text{fall}}) \dots\dots\dots(3)$$

$$LS_{\mu} = \sum_{i=1}^n \frac{LS_i}{n} \dots\dots\dots(4)$$

where LS is i is the LS of different year, n is the number of the evaluated year.

3. DATA

3.1 Site description

The study site, which is located in a arid and semi-arid region, western China (Fig.1), covers an area from 99°48'E to 102°00'E in longitude and from 40°24'N to 42°55'N in latitude (about 202.7×243.6km, 30,333km²). The land cover types vary greatly in this area, including forest which has dominated by *Populus euphratica* trees, grassland, barren deserts like Gobi, salt land, and water body. Land cover variability is strongly influenced by the seasonal water supply of melting ice from mountains with elevation higher than 2000m in summer. The water supply in this area creates a strong seasonality in vegetation growth: cover areas, the amount and the spatial patterns of the green cover areas. Therefore, summer is the time of the critical growing season when vegetation activity is at its maximum. The characteristic vegetation types constitute mixtures of grasslands and *Populus euphratica* forests. In general, the precise geographic location of Ejin Oasis is difficult for distinguishing because these physical characteristics change over time and space.

3.2 Time series of bi-weekly NDVI

The moderate resolution imaging spectroradiometer (MODIS) satellite imagery provide long time serial observation data with a high temporal resolution of about 1 to 2 days from 2000. The MODIS instrument onboard TERRA or AQUA satellites has proven to be used in comprehensive ways to assess and monitoring the spatial patterns of land surface, functions of the environment and the interactions between the atmosphere, the ocean, and the biosphere. The MODIS instrument onboard the Terra satellite has been providing NDVI bi-weekly maximum composites over land since February 2000. In addition, the MODIS instrument onboard Aqua has been providing the NDVI composites since July

2002. The satellite images from Terra/MODIS were used in this study in evaluating vegetation dynamics in arid and semi-arid environments.

They involve transformations of the red (620-670 nm), near-infrared (841-876 nm), and blue (459-479nm) bands designed to analyze the vegetation activities and allow for comparisons of spatial and temporal variations in terrestrial ecosystems. The MODIS standard VI products are labeled as:

- ❖ MOD13A1:16-day 500-m VI (high resolution/globally produced)
- ❖ MOD13Q1:16-day 250-m VI (high resolution/limited production)
- ❖ MOD13A2:16-day 1-km VI (standard resolution/globally produced)
- ❖ MOD13A3: Monthly 1-km VI (standard resolution/globally produced)

The satellite images used in this study are the MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid. The biweekly image composition algorithm relies on multiple observations over a 16-day period and operates on a per-pixel basis to generate the images. All the MODIS biweekly composite images used in this study have a spatial resolution of 250m.

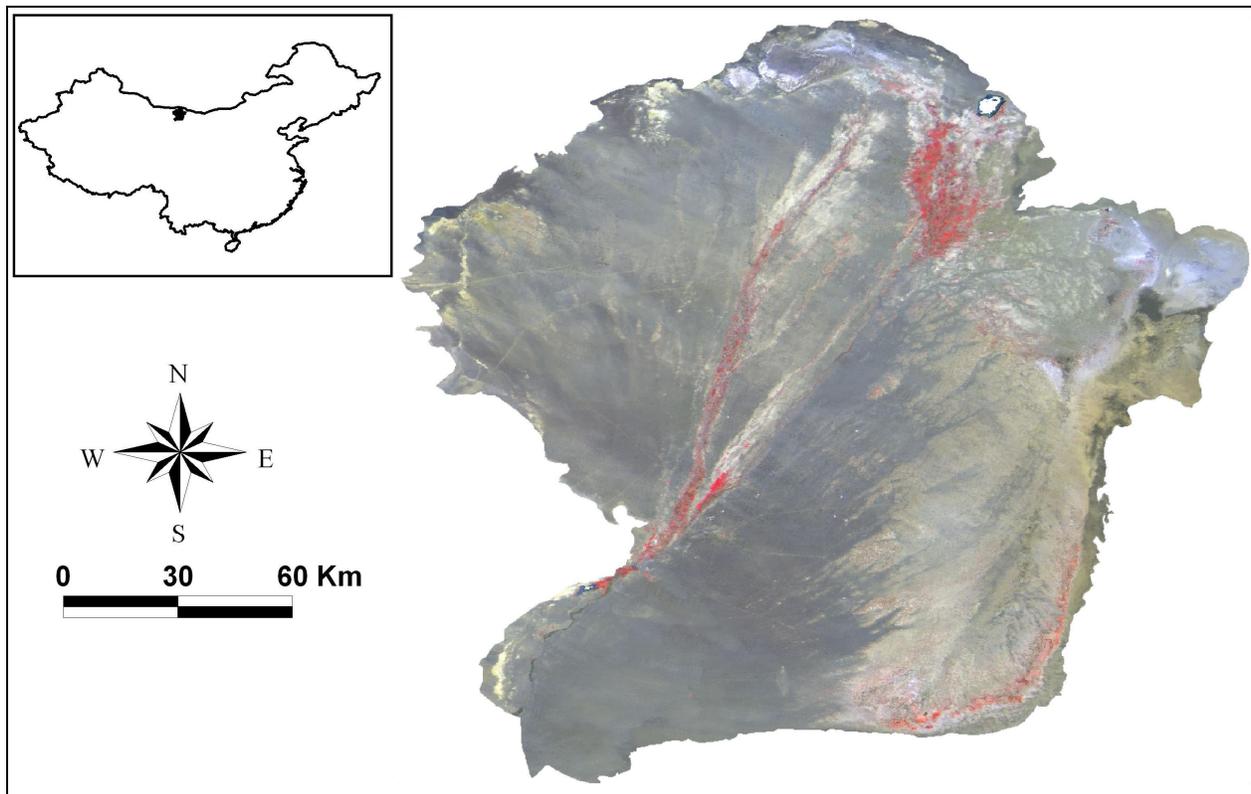


Figure1 The map of study area. The MODIS image composed by blue, red, and near-infrared band shows the spatial distribution of land surface of Ejin, western China. The areas with gray color are one part of the Gobi desert. The Ejin oasis ecosystem is mainly distributed over the northern part of the study area.

4. RESULTS

4.1 Spatial distribution of green cover dynamics

The green cover time-series of the seasonal composites shows a distinct seasonal pattern (Fig.2). The green cover areas in summer are larger than other seasons for the year 2000-2005 (Table 1). From 2000 to 2005, the green cover area varies from year to year, ranging from 1,999km² to 2369km². A sudden expansion of the green cover area in summer was observed in 2004 to reach its maximum area during the study period. The green cover areas began to increase in spring and decrease again in winter with a peak in summer, which conforms to vegetation growth in Mongolia(Yu et al., 2004). The seasonal green cover areas in Ejin show the highly variable nature of most arid and semiarid environments.

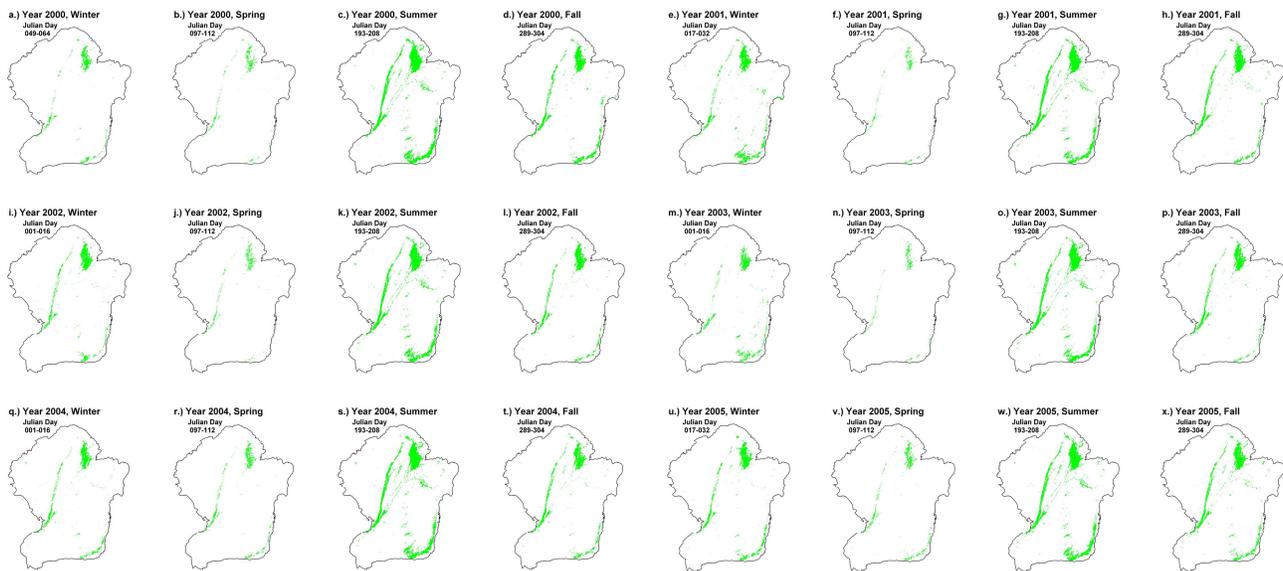


Figure 2 Green cover maps with different seasons during the period between 2000 and 2005. The green cover maps from Fig. 2a to Fig. 2d are shown the seasonal variation in 2000. The green cover maps from Fig. 2e to Fig. 2h are shown the seasonal variation in 2001. The green cover maps from Fig. 2i to Fig. 2l are shown the seasonal variation in 2002. The green cover maps from Fig. 2m to Fig. 2p are shown the seasonal variation in 2003. The green cover maps from Fig. 2q to Fig. 2t are shown the seasonal variation in 2004. The green cover maps from Fig. 2u to Fig. 2x are shown the seasonal variation in 2005.

Table 1 The seasonal green cover areas (km²) in Ejin during the period between 2000 and 2005

	Winter	Spring	Summer	Fall
2000	526	321	2215	1305
2001	1244	222	2022	1258
2002	954	317	2079	965
2003	756	223	1999	972
2004	883	542	2369	1188
2005	1086	491	2183	1475
Average	908	353	2144	1194

4.2 Landscape Sensitivity Analysis

There are innumerable ways that changes to systems and changes to the landscape, and it is not always easy to separate out which is cause and which is effect. In this study, the vegetation conditions are viewed to be a final result after the complicated ecological functions and interactions on land surfaces. Thus, the NDVI which is used in assessments of various biophysical parameters, such as green cover, biomass, LAI, and fAPAR was selected in assessing landscape sensitivity.

Fig. 3 shows the spatial pattern of landscape sensitivity during the period between 2001 and 2005. The areas with high values in red colors are distributed over the northern part of the study area. These areas are composed of forest and grassland ecosystems. Moreover, there are two belt zones with high values in green color are distributed over the central part of the study area. The land types of these areas are mainly river channels and the transition zones between river channels and deserts. The identified changes in land surfaces are detected by using the index of LS_{μ} in this study. The used method is standard remote sensing applications, although generally not used for assessments of landscape sensitivity. The map shows a coincidence between the spatial pattern of sensitive ecosystems (forest ecosystem, grassland ecosystem, and river ecosystem) in Ejin and the result of landscape sensitivity analysis. In the arid and semi-arid environments, this method of assessing landscape sensitivity has proven the usefulness and convenience to quick assessment and monitoring.

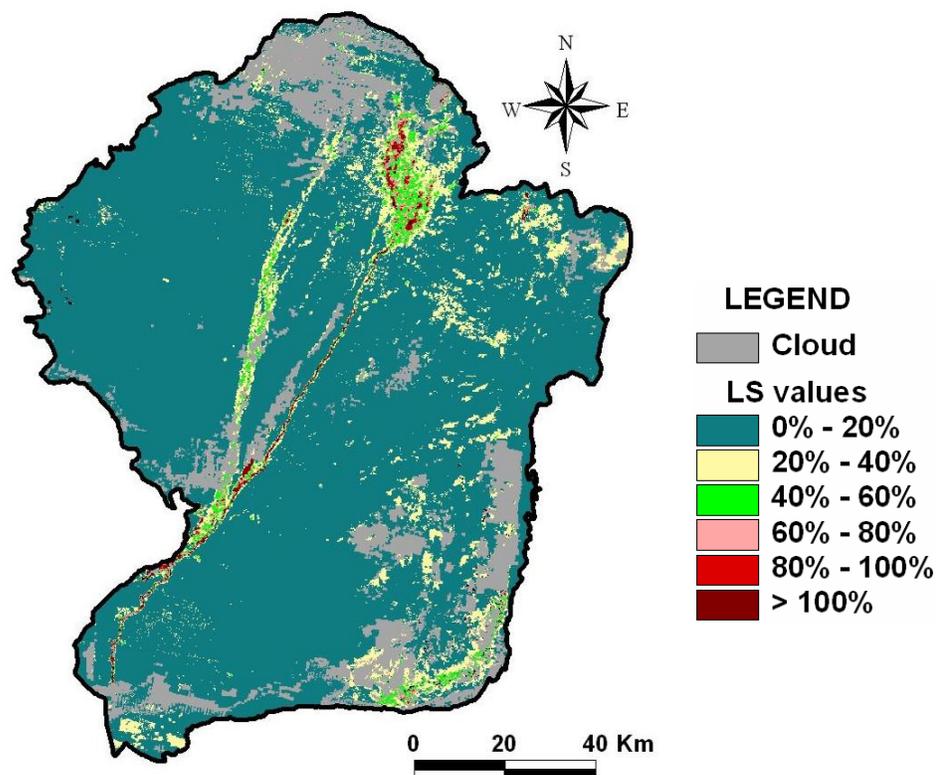


Figure3 The map of Landscape sensitivity in Ejin, western China. The result is calculated by five-year data to reduce the noise from satellite instruments, atmosphere, and other sources of noises. The areas with high sensitivity (the value higher than 60%) are shown with red and dark red colors. The areas with low sensitivity (the value lower than 20%) are shown with turquoise color. The other areas with median sensitivity (the value ranging from 20% to 40%) are shown with light yellow color.

5. CONCLUSIONS

Satellite measurements of Ejin green cover dynamics during the period between 2000 and 2005 have provide a comprehensive picture of the patterns of land surface inter-annual variation and trends. The result indicates that the assessment and monitoring using remotely sensed images are effective for understanding the inter-annual and seasonal variations of land surfaces, especially in arid and semi-arid environments. The green cover areas in Summer are the peak of growing season and are larger than other seasons. The seasonal changes of green cover area in Ejin are stable and are shown a regular pattern in vegetation dynamics in a year. In addition, the green cover areas in spring are smallest, which the total area is usually lower than 300 km² (the total area in summer is usually higher than 2000km²).

An attempt in combing the concept of landscape sensitivity and remote sensing techniques is successfully shown in Fig. 3. The likelihood of change can be detected by using remote sensing techniques. The average of five year's LS value make the value of LS shown the real condition in NDVI changes. Our study showed that it was possible to derive important parameters linked to landscape sensitivity from MODIS imagery and the derived imagery, such as NDVI time-series data. Such a time-series monitoring system based on MODIS imagery is useful in arid and semi-arid environment. The result of landscape sensitivity analysis has proven the effectiveness of the method in assessing landscape sensitivity of the year of 2001-2005. This information of landscape sensitivity can be used to detect "hot spots" of sensitive ecosystems in arid and semi-arid environments. The spatial distribution of landscape sensitivity will help governments to improve the efficiency in landscape conservation.

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