Analysis of desertification and wood land distribution: A case study on the Balinyou Banner of Inner Mongolia, China

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Abstract - Desertification is a serious threat to the sustainability of the environment and to human habitation. Kerqin sandy land is the largest sandy land in China, and is one of the most important origins of sandstorms in Northern China. Land desertification and frequent sandstorms in the spring strongly affect the growth of grassland vegetation and crops, and the effective of eco-environment in this region. Scholars have proposed different measures to control desertification for different regions and to reduce its influence. Planting shelterbelt is one of the most common measures to prevent desertification in Kerqin sandy land. In this study Remote Sensing data were used to monitor sandy land and forest areas from 1977 to 2009. The effectiveness of shelterbelt as a defence against desertification was also assessed.

Keywords: Balinyou Banner, shelterbelt, desertification, Tassel Cap, Expert classifier.

1. INTRODUCTION

Different definitions of desertification are used in previous literature. Desertification was defined as the reduction or loss of biological or economic productivity resulting from land use or human activities and habitation patterns in the International Agreement on Combating Desertification held in Paris in 1994. Barrow pointed out that desertification is usually expressed in terms of measurable physical or biological conditions or processes that can be used as surrogates for productivity loss (Barrow, 2009). However, the definition that “desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities” has been widely accepted.

Desert region often has poor environment and road, moreover, because of low temporal and spatial resolution, traditional ground based measurement method cannot meet the requirements of desertification monitoring and forecasting very well. The technology of satellite remote sensing can provide calibrated, quantitative, repeatable, and cost-effective information for large areas and can be related empirically to field data. Remote sensing techniques provide important tools for generating information on land degradation status and its geographical extent.

To control desertification and to reduce its influence on grassland and farmlands, many measures have been developed and implemented successfully in China. Constructing wheat-straw checkerboards and planting indigenous dune-adapted shrubs are accepted as common measures to restore vegetation on desertified sand dunes. These measures have been successful in accelerating land restoration, decreasing wind erosion, improving soil characteristics and facilitating plant establishment and spread. In the Balinyou Banner, an important measure to control sand is planting shelterbelts and scrubs. The shelterbelts are mainly close to farmland, roads, and some buildings, and are difficult to identify by Landsat data. The scrubs are mainly planted by aerial seeding. In this study, we only study the relationship between scrub cover and desertification.

2. STUDY AREA

Balinyou Banner is located in Northern Chifeng City, Inner Mongolia. Its main economic activities are pasture and animal husbandry. It has an area of 9,834 km^2, and it is bounded at the north by Daxinganling Mountains and at the south by the Xar Moron River. The Balinyou Banner is located in an agro-pastoral transitional and fragile ecological zone with an annual mean precipitation of 344.4 mm and evaporation rate of > 1,500 mm. Its climate is semi-arid and its zonal vegetation is sparse grassland; hence, there are natural factors that can potentially lead to the occurrence and development of desertification, which are exacerbated by economic activities. Broad and rich grassland resources are the main pillars of economic development in the Balinyou Banner; however, since the relationship between economic development and environmental protection is not well understood, long-term uncontrolled exploitation led to further deterioration of the grassland ecology.

3. DATA AND METHODOLOGY

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3.1. Data basis

The Landsat data was acquired to detect land use/cover changes and to evaluate the land degradation status within the study area. In this study Landsat MSS in 1977, TM in 1985, 1992, 1995, 2006 and 2009, ETM+ in 1999 were used. All data were composed of vegetation growing season (August, and September) with a cloud cover of less than 2%. In order to get a meaningful analysis, a rigorous pre-processing scheme for all the images is necessary. The geometric correction was performed for all the images with the resulting root mean square error (RMSE) did not exceed 0.3 pixels. Data of each study year contains 2 scenes of image (P/R: 120/30 and 120/31). All processes were conducted during the software ERDAS IMAGE 2010.

3.2. Methodology

The land cover changes are mainly characterized by the change of landscape pattern, vegetation biomass or cover, and micrometeorological conditions. Therefore, the indicators that reflect these changes can be selected to study land cover changes. Considering the strong correlation among indicators in assessing one aspect of land surface condition, we only selected one indicator to represent one aspect of land surface conditions. In this study, the tasselled cap brightness (TCB), Normalized difference vegetation index (NDVI) and broadband albedo were used to characterize landscape pattern vegetation biomass, and micrometeorological conditions of land surface respectively.

3.2.1 Tasseled Cap

The tasseled cap transformation was presented in 1976 by R.J. Kauth and G.S. Thomas. The tasseled cap transformations of Landsat data provide a mechanism for data volume reduction and enhanced data interpretability by emphasizing structures in the spectral data which arise as a result of particular physical characteristics of scene classes. Furthermore, the tasseled cap transformation results are directly related to important physical parameters of the land surface (Chen and Rao, 2008). Due to the less vegetation cover and high reflectance in desert areas, brightness derived from the tasseled cap transform (here we called TCB) is an important index in desertification studies (Equations (1)-(3)).

$$TCB_{MSS} = 0.332B_1+0.603B_2+0.675B_3+0.262B_4 \quad (1)$$

$$TCB_{TM} = 0.291B_1+ 0.249B_2+ 0.481B_3+ 0.557B_4+ 0.444B_5+ 0.171B_7 \quad (2)$$

$$TCB_{ETM+} = 0.356B_1+0.397B_2+ 0.390B_3+ 0.697B_4+ 0.229B_5+ 0.160B_7 \quad (3)$$

Where B_i represents the band number of the Landsat data.

3.2.2 Normalized Difference Vegetation Index (NDVI)

Vegetation indices are derived mainly from reflectance data of discrete red (R) and near-infrared (NIR) bands. These indices operate by contrasting intense chlorophyll pigment absorption in the R against the high reflectance of plant materials in the NIR. Normalized difference vegetation index (NDVI) is gaining importance in global change studies and is the most widely used index, particularly in the analysis of data taken from satellite platforms (Equation 4).

$$NDVI = \frac{NIR-R}{NIR+R} \quad (4)$$

Where NIR is the reflectance in the near infrared and R is the red waveband reflectance.

3.2.3 Broadband Albedo

An increased use of satellite data to monitor the albedo of arid lands has arisen from the dual importance of albedo as a potential indicator of arid land degradation and as a physical parameter with possible impacts on climate. Albedo may serve as an indicator of degradation because removal of vegetative cover exposes more of the soil background, which is generally highly reflective. Albedo and other satellite measures of overall reflectivity thus tend to increase when overgrazing or prolonged drought lead to decreases in vegetative cover, and reflectivity decreases with recovery (Musick, 1986). Some studies found that land surface broadband albedo is a critical variable affecting the earth's climate. In semiarid regions, an increase in albedo leads to a loss of radiation energy absorbed at the surface, and convective overturning is reduced. As a result, precipitation decreases. Evaporation may also decrease, further inhibiting precipitation (Liang, 2000). In this study, we adopted broadband albedo that determined by the combination of narrowband albedo to assess the micrometeorological conditions of land surface. Broadband albedo was then calculated according to its relationship with each narrowband. The broadband albedo calculation for Landsat MSS and Landsat TM/ETM+ are expressed by Equations (5) and (6):

$$Albedo_{MSS} = 0.228\alpha1+0.217\alpha2+ 0.182\alpha3+ 0.373\alpha4 \quad (5)$$

$$Albedo_{TM\,/\,ETM+} = 0.356\alpha1+ 0.130\alpha3+ 0.373\alpha4+ 0.085\alpha5+ 0.072\alpha7 - 0.0018 \quad (6)$$

where $Albedo_{MSS}$ and $Albedo_{TM\,/\,ETM+}$ represent the broadband albedo of Landsat MSS and Landsat TM/ETM+; α1-7 are narrowband albedo for each band of Landsat MSS (band 1-4) and Landsat TM/ETM+. Narrowband albedos are equal to the surface reflectance of these bands (Equation (7)).

$$\rho_\lambda = \frac{\pi * L_\lambda * d^2}{ESUN_\lambda * \cos\theta_s} \quad (7)$$

Where: ρ_λ = Unitless plantary reflectance.

L_λ= spectral radiance (from latter step Equation (8)).

d = Earth-Sun distance in astronmoical units.
$ESUN_\lambda$ = mean solar exoatmospheric irradiances.
θ_s = solar zenith angle.

3.2.3 Expert Classification

The expert classification provides a rules-based approach to multispectral image classification, post-classification refinement, and GIS modeling. In essence, an expert classification system is a hierarchy of rules, or a decision tree, that describes the conditions under which a set of low level constituent information gets abstracted into a set of high level informational classes. A rule is a conditional statement, or list of conditional statements, about the variable's data values and/or attributes that determine an informational component or hypothesis. Multiple rules and hypotheses can be linked together into a hierarchy that ultimately describes a final set of target informational classes or terminal hypotheses. Confidence values associated with each condition are also combined to provide a confidence image corresponding to the final output classified image.

Several works have demonstrated the expert classification generated in a supervised fashion provide an accurate and efficient methodology for land cover classification problems in remote sensing. It can decrease the errors created by the same bodies that reflect different spectra and the same spectra reflected by different bodies. The expert classification is more suitable in the classification of regions with complex terrains. In this study, field investigation results in 2009 and 2010 were used to determine the threshold values of each node for the expert classification of the seven stages of images of Balinyou Banner.

4. RESULTS AND DISCUSSION

4.1 Results

Expert classification was used. At least nine classes (forest, crop land, grasslands, semi-fixed dune, scrub land, mobile dune, water bodies, built-up land, and others) were mapped (Figure 1). Accuracy of the classification results for all study years was checked according to field data and a land-use map (1:4,000,000 vector types, Institute of Geography, Chinese Academy of Sciences). Satisfactory classification results were obtained based on the accuracy results. The average total accuracy of four periods is higher than 87.3%, and the highest total accuracy and conditional kappa statistic in the assessment for 1999 are 89.31% and 88.56%, respectively. Based on these results, the forest was mainly distributed northwest of Balinyou Banner, and mobile sand was mainly distributed in the southeast and northwest. Cropland was mainly distributed along the rivers, and grasslands occupied most of the study area.

4.2 Discussion

4.2.1 Land cover change

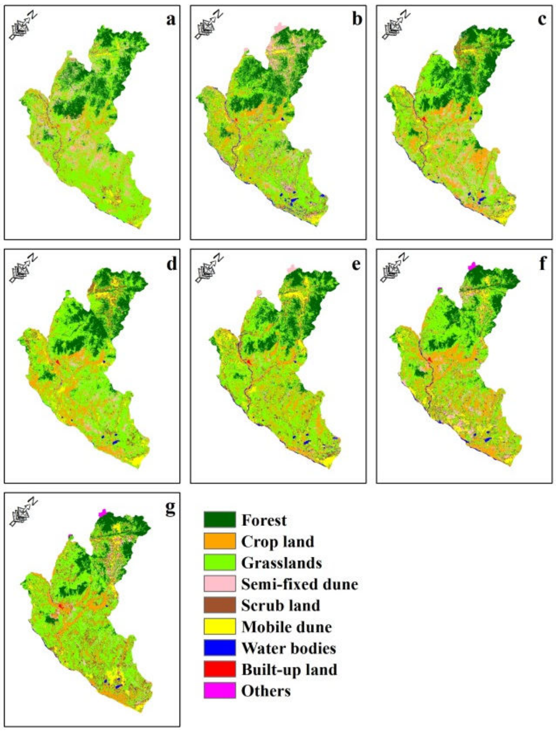

Figure1. Land cover map of Balinyou Banner in 1977(a), 1985(b), 1992(c), 1995(d), 1999(e), 2006(f) and 2009(g)

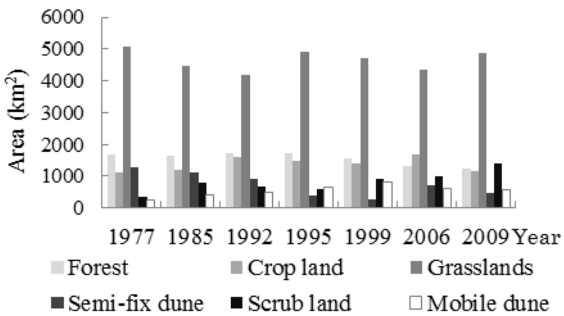

Figure2. Result of the main land covers from 1977 to 2009

The Balinyou Banner is a farming and animal husbandry county whose economy is mainly based on grazing. From the figure2, the grasslands areas were larger than those of other land classes in each state. However, due to overgrazing, the grassland area declined. In the 1980s, land reclamation was the main human activity that affected land use and land cover change. As a result, grasslands area decreased, and that of cropland increased from 1977 to 1992. Due to the implementation of policies such as the Banning Grazing and Grain for Green Project, the area of grassland increased. From Figure2, the area of croplands fluctuated, and this trend was influenced by the level of precipitation. The decrease in cropland area was also followed by a low level of precipitation during the same and the preceding year (Figure3).

In 1978, the Chinese Central Government initiated a wide afforestation program, the Three North Forest Shelterbelt Program, in the three northern parts of China (Northeast, North, and Northwest China). The key goal of this program is to improve forest coverage in the arid and semiarid regions of China from 5% to 15% in the next decades. The Balinyou Banner is located at the boundary of the area covered by the Three North Forest Shelterbelt Program. However, the forest (mostly alpine woodland) cover in this area changed very little from 1977 to 1995, and then decreased from 1995 to 2009. This is because the shelterbelts in the Balinyou Banner are composed mainly of scrub. These scrub lands mainly contained aerial seed Caragana and artificially propagated Siberian apricot. The scrubland area increased, especially in 1985 (Figure2). To control desertification, the Chinese government aerial seed scrub every year; however, the mobile dune area increased from 1977 to 1999, and decreased since then. These observations imply that scrubs can control desertification if the area is sufficiently large. The area of semi-fixed dunes decreased as the scrub and mobile dune increased; this implies that the scrubland mainly transform from semi-fixed dunes.

4.2.2 Desertification and climate changes

Generally, factors affecting desertification can be divided into two categories, namely, climatic variability and human activities. Desertification often occurs in arid, semiarid and dry sub-humid areas where high temperature is very common. Human activities include overgrazing, overexploitation, deforestation, and poor irrigation practices.

Annual rainfall varied from 158.6 mm in 1988 to 551.5 mm in 1991. The 10-year average rainfall (figure4) shows that in the Balinyou Banner, the recent 10 years had the lowest rainfall; the mobile dunes decreased, the scrubland increased, and the amount of semi-fixed dunes increased in 10 years. The 10-year average rainfall increased from 1971 to 2000, the mobile dunes decreased, and the semi-fixed dunes increased. These trends suggest that desertification has no relationship with rainfall in the Balinyou Banner.

Temperature is an important factor that affects atmospheric circulation, and, consequently, rainfall. It also directly affects evaporation. The annual temperature increased and the mobile dunes had the same trend with temperature, but the semi-fixed dunes had the opposite trend. Temperature also had a slight relation to desertification in the Balinyou Banner.

5. CONCLUSIONS

Desertification causes a reduction in the ability of land to support life. It affects wild species, domestic animals, agricultural crops, and humans. In this study, indicators were selected according to three different aspects of the responses of land surface conditions to desertification. Based on the complex terrain conditions, expert classifiers were selected to sort the Landsat data over the past 30 years. In this study, the average overall accuracy of assessments in the three periods is higher than 87%. The analysis also shows that the Three North

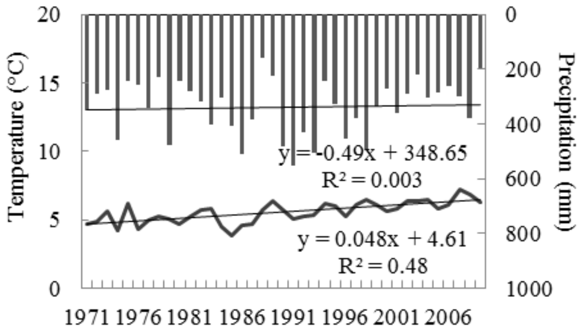

Figure3. Precipitation and temperature of Balinyou Banner from 1971 to 2009

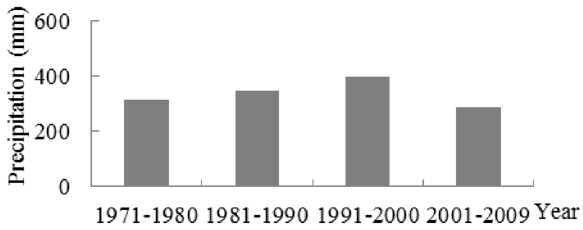

Figure4. 10 years average precipitation of Balinyou Banner

Shelterbelt Project in the Balinyou Banner mainly addressed scrubland areas. In 2006, the number of mobile dunes decreased when the scrubland area reached 1,007 km^2. Desertification in the Balinyou Banner was slightly related to climate during the period covered by the study.

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