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Advances in Space Research 57 (2016) 64–77

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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Assessment of land cover change and desertification using remote sensing technology in a local region of Mongolia

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Received 15 January 2015; received in revised form 11 August 2015; accepted 6 October 2015
Available online 14 October 2015

Abstract

Desertification is a serious ecological, environmental, and socio-economic threat to the world, and there is a pressing need to develop a reasonable and reproducible method to assess it at different scales. In this paper, the Hogno Khaan protected area in Mongolia was selected as the study area, and a quantitative method for assessing land cover change and desertification assessment was developed using Landsat TM/ETM+ data on a local scale. In this method, NDVI (Normalized Difference Vegetation Index), TGSI (Topsoil Grain Size Index), and land surface albedo were selected as indicators for representing land surface conditions from vegetation biomass, landscape pattern, and micrometeorology. A Decision Tree (DT) approach was used to assess the land cover change and desertification of the Hogno Khaan protected area in 1990, 2002, and 2011. Our analysis showed no correlation between NDVI and albedo or TGSI but high correlation between TGSI and albedo. Strong correlations (0.77–0.92) between TGSI and albedo were found in the non-desertification areas. The TGSI was less strongly correlated with albedo in the low and non desertification areas, at 0.70 and 0.92; respectively. The desertification of the study area is increasing each year; in the desertification map for 1990–2002, there is a decrease in areas of zero and low desertification, and an increase in areas of high and severe desertification. From 2002 to 2011, areas of non desertification increased significantly, with areas of severe desertification also exhibiting increase, while areas of medium and high desertification demonstrated little change.

Keywords: Desertification; Sand; Assessment; Correlation; Topsoil Grain Size Index

1. Introduction

Land degradation (LD) is a complex phenomenon. It reduces soil fertility (Kassas, 1999) especially in dry regions, and sometimes leads to local desertification phenomenon (Rubio and Recatala, 2006). LD causes different aspects of natural resource depletion such as degradation of soil, vegetation and water. Furthermore, LD has a negative influence on bio-physical and socio-economic processes that society has defined as important components in various spatial and temporal scales (Lal and Stewart, 1990; Puigdefabregas and Mendizabal, 1998; Garcia Latorre et al., 2001).

Desertification is best to be understood as an extreme case of land degradation, which is expressed in a persistent reduction or loss of biological and economic productivity of lands (UNCCD 2010). Desertification can be also defined as “Land degradation in the arid, semiarid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities”

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http://dx.doi.org/10.1016/j.asr.2015.10.006
0273-1177/

(UNCCD 1995). Globally, desertified land amounts to $3.6 \times 107\ km^2$, which covers 24.1% of Earth's land surface and affects about one-sixth of the world's population, much of whom live in poverty (Middleton and Thomas, 1997). In recent years, the notion of desertification has been related to the loss of ecosystem services resulting from the effect of anthropogenic disturbances or climatic variations in dryland ecosystems (D'Odorico et al., 2013).

Remote sensing information with vegetation index and land surface albedo have been studied (Zeng et al., 2006; Pan and Qin, 2010). Additionally, vegetation cover is an important indicator for evaluating the extent of vegetation restoration in degraded sandy grasslands (Zhang et al., 2004). NDVI (Normalized Difference Vegetation Index) is one of the most extensively applied vegetation indices for its sensitivity to the presence, density and condition of vegetation. It is a simple numerical indicator that can be used by remote sensing measurements. NDVI provides a crude estimate of vegetation health and acts as a means of monitoring changes in vegetation over time. NDVI can be utilized as a cost effective and reliable approach for national reporting on several UNCCD core indicators. The Normalized Difference Vegetation Index (NDVI) has been most commonly used to map spatial and temporal variation in vegetation (Tucker, 1979). Thus, we have thus additionally employed NDVI as an indicator of land cover change and desertification.

The texture of topsoil is closely related to land degradation. According to Zhu et al. (1989), different extents of desertification result in different topsoil textures – the more severe the desertification, the coarser the topsoil grain composition. More recently, Fu et al. (2002) found that overgrazing can accelerate soil wind erosion and result in topsoil coarsening. Zhao et al. (2005) showed that the sand content of a severely eroded cropland is higher than average. Coarsening of topsoil is a visible sign of land degradation, thus the grain size composition of topsoil can potentially be used as an indicator of land degradation. It is thus possible to monitor desertification by the change in Topsoil Grain Size in arid and semi-arid areas using remote sensing techniques.

Topsoil Grain Size Index (TGSI) is only applicable for bare or sparsely vegetated areas. The obtained TGSI results appear to be promising for identifying and highlighting sand accumulations in the study area (Hadeel et al., 2010). The negative TGSI value indicates areas covered by vegetation, and positive TGSI represents coarse sand (Xiao et al., 2006). Given that one rainfall can significantly increase the vegetation cover, NDVI is not precise enough to indicate the actual degree of desertification. In order to develop a practical index associating the physical properties (mechanical composition) of topsoil in monitoring changes in surface soil texture using remote sensing, Xiao et al. (2006) analyzed the correlations between several of the aforementioned spectral indices and the topsoil grain size composition. The best correlation was found between TGSI and fine sand and silt–clay contents of topsoil.

Some studies showed that increasing land surface albedo implies a degradation of land quality (Riobinove et al., 1981). Clay soils can maintain high moisture content in the presence of a water supply, while sandy textured soils drain and dry out much more rapidly. Because of the differences in the resulting soil moisture content between the texture classes, there are differences in the reflectance and absorbance characteristics of the texture classes as well as the land surface albedo (Dobos, 2003). A variety of factors influence the ability of plants to reflect sunlight. At the most simplistic level, dark coloration provides the greatest absorption and hence the lowest land surface albedo. Leaf shape is quite important because leaf shapes provides reflectivity. This effect explains why conifer forests tend to have lower land surface albedo than angiosperm or broadleaf forests. Furthermore, leaf aspect is also contributory – leaves surfaces more parallel to the ground surface demonstrating higher land surface albedo (Budikova, 2010). Land surface albedo plays a major role in the energy balance of the Earth's surface, as it defines the rate of the absorbed portion of incident solar radiation. The albedo value ranges from zero to one. A value of zero refers to a black body, a theoretical medium that absorbs 100% of incident radiation. Albedo values ranging from 0.1 to 0.2 indicate dark-colored, rough soil surfaces, while values around 0.4–0.5 represent smooth, light-colored soil surfaces. Albedo varies diurnally and seasonally because of the changing angle of the sun (Dobos, 2003; Matthews, 1984; Kotoda, 1986). In general, the lower the sun's angle, the higher the albedo.

The objectives of this study are (1) to assess the land cover change and desertification process with remote sensing data (1990, 2002 to 2011) and (2) to identify a pixel-based relationship between NDVI, TGSI, and land surface albedo in the desertification grade. In this study, the study area was classified by the level of desertification, and the relationship between the desertification level and the three variables was tested; this relationship was examined by using pixel-based regression analysis.

2. Study area

The Hogno Khaan nature reserve is located between the 47°23′ and 47°38′N latitudes and the 103°30′ and 103°50′E longitudes. It is the region of Khangai-Khentii ranges, and this reserve shares the boundaries of three different geographic regions in Mongolia. The nature reserve covers $835.45\ km^2$ of land, and is situated in the area of Gurvanbulag and Rashaant sums of Bulgan Province, and Burd sum of Uvurkhangai Province. The Elsen Tasarkhai sand dune, located in this area, comprises the Mongol Els in the south and the Hogno Tarnyn Els in the north. Elsen Tasarkhai sand is sodden under its surface, therefore, *shrubberies* such as *Ulmus pumila*, *Salix ledebouriana* grow in the area. The Elsen Tasarkhai sand is surrounded by mountains Hogno Khaan to the north and mountains Ikh Mongol to the south (Fig. 1). This area contains