Ecosystem Services 30 (2018) 172–180

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Assessing the impact of desertification dynamics on regional ecosystem service value in North China from 1981 to 2010

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ARTICLE INFO

Article history:
Received 27 December 2017
Received in revised form 12 February 2018
Accepted 3 March 2018

Keywords:
Desertification
Ecosystem service value
Impact assessment
North China

ABSTRACT

Deserts and desertified land form an important ecosystem that supports the inhabitants of dry land areas, and desertification dynamics have a significant impact on the regional Ecosystem Service Value (ESV). In this paper, the desertification dynamics in North China from 1981 to 2010 and their impact on the regional ESV were analyzed by decomposing the processes of desertification. The results showed that the area and structure of deserts and desertified land had greatly changed, and the area of land that experienced desertification reversion was higher than expansion. Desertification reversion was the key process that promoted an increase in the total ESV of the whole research region; the increment of the ESV can be attributed to the reversal from deserts and desertified land to non-desertified lands reached 90.13 billion yuan. Desertification expansion from undegraded grassland to deserts and desertified land was the dominant process that produced a decreased in the regional ESV. Horqin grassland, Hetao plain, and Wumeng Qianshan and Tumote plain had a higher sensitivity than other sub-regions, and Alashan plateau had the lowest sensitivity among all of the sub-regions. To enhance economic development and the ecological services supply, "win–win" measures should be used for sub-regions with different sensitivities.

1. Introduction

Ecosystem services are the conditions and processes through which natural ecosystems sustain and fulfill human life, including provisioning services (such as food, water, timber, and fiber), regulating services (such as climate, floods, disease, waste, and water quality), cultural services (such as providing recreational, aesthetic, and spiritual benefits), and support services (such as soil formation, photosynthesis, and nutrient cycling) (Costanza et al., 1997; Daily et al., 2000; MA, 2005; Redford and Adams, 2009). Ecosystem services have a close relationship with land use and land cover, and they vary greatly at different temporal-spatial scales (Rounsevell et al., 2012; Tolessa et al., 2017; Schirpke et al., 2017; Costanza et al., 2014). Identifying and measuring the impact of land use and land cover change on regional ecosystem services is an effective way to assess the costs and benefits to the environment and support sustainable management decisions (Song and Deng, 2017; Liang et al., 2017).

As one of the most important ecosystems and land cover types on the planet, deserts and desertified land provide some critical ecosystem services to support their inhabitants and economic-social development, including carbon fixation and oxygen release, hydrological regulation, soil conservation and sand fixation, biodiversity maintenance, and ecological tourism (Richardson, 2005; Gu et al., 2017), which create ecological and economic value (Kroeger and Manalo, 2007; Galati et al., 2016). Over the past few decades, deserts and desertified land have changed greatly due to climate change and human activities, which has resulted in a significant alteration to these areas' global and regional ecosystem services (Liao et al., 2015; Liu et al., 2014; Sherratt and Synodinos, 2012). For example, in the process of desertification reversion, the dominant species, plant community structure, and landscape pattern change significantly; annuals gradually evolve into shrubs and perennial herbs, and the species richness, vegetation coverage, and landscape heterogeneity increase. The soil sand content decreases, as well (Liu and Gong, 2012; Beggy and Fehmi, 2016). All these changes might lead to the enhancement of ecosystem services. Previous studies have shown that the ecosystem service in the Ugan-Kuqa River Delta Oasis of China increased from 2000 to 2008, which could mainly be attributed to the increasing areas of wetland and high-cover grassland (Sawut et al., 2013). Ammann et al. (2014) found that deserts and desertified land reverted to

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https://doi.org/10.1016/j.ecoser.2018.03.002
2212-0416/

forested areas that stabilized the soil, reduced water and wind erosion, and maintained nutrient cycling.

Although there is some argument over the range of services provided by natural ecosystems, investigating and assessing the value of ecosystem services is still a valuable method for analyzing the impact of land use and land cover change on regional ecosystem services; it has been widely used on global and regional scales since the 1990s (Downing et al., 1999; TEEB, 2010; Tallis and Polasky, 2011; Dearing et al., 2012; Wu et al., 2013; Crespin and Simonetti, 2016; Szabo et al., 2016). For example, Costanza et al. (1997) and Daily et al. (2000) estimated the value of global ecosystem services by using a market valuation method, which made it possible to quantitatively analyze and compare the change in the ecosystem services. Richard et al. (1997) developed a non-market value evaluation based on systematically summarizing the value of the wetland ecosystem service over many years. However, these studies downplayed the importance of the ecosystem services provided by deserts and desertified land and set a small value for these areas (MA, 2005; Adekola et al., 2015; Zhang et al., 2015; Quintas-Soriano et al., 2016; Zoderer et al., 2016). The differences in the ESV of land with varying degrees of desertification were not considered when they were used to assess their impact on regional ecosystem services, which might lead to a misunderstanding of the effect of desertification control and sustainable land management.

China is suffering from desertification. According to the fifth National Desertification Survey statistics (State Forestry Administration of China, 2015), the area of desertified land in China reached 1,721,200 km^2 in 2014. The central and local governments have made efforts to combat desertification through various projects, including the Grain for Green Project, the Beijing and Tianjin Sandstorm Source Treatment Project, and the Natural Forest Protection Project, as well as through policies, such as the "no grazing" statute (Wang et al., 2010; Miao et al., 2015; Yang et al., 2015). Rapid urbanization and intensive mining are creating pressure on desertified land (Potchter and Ben-Shalom, 2013; Wang et al., 2017; Fu et al., 2017), which combined with climate change, have a powerful impact on desertified land. The aims of this study were to (1) investigate the change in the ESV of deserts and desertified land in North China and (2) evaluate how desertification dynamics affect the regional ESV and explore their spatial heterogeneity. This work provides a scientific basis for decisions about desertification control and ecological construction in China.

2. Methods and materials

2.1. Study area

Deserts and desertified land in China are mainly distributed in the northern regions across the semi-humid, semi-arid, and arid zones. We studied a region in this area measuring 3,022,848 km^2 (Fig. 1). The climate characteristics of this region exhibit spatial heterogeneity. There is little rainfall, and it is unevenly distributed; the average annual precipitation is only 0–450 mm. The average temperature is about 5.7 °C, the average annual sunshine duration is 2,807 h, and the average wind speed reaches 2.3 m/s. Most of soils in this area are chestnut soil, brown soil, brown desert soil, mattic soil, and sandy soil. The vegetation, land use, and land cover in the study area also have great spatial heterogeneity, including oasis irrigation agriculture, rainfed agriculture, semi-humid and semi-arid steppe grassland, desert grassland, and alpine meadow steppe. The ecological, social, and rehabilitation development of the region we studied has made some progress over the last few decades. However, the rapid increase in the population, urbanization, and intensive mining activities have created pressure on the region, increasing the risk of land desertification (Gilbertson et al., 2008; Wang et al., 2016).

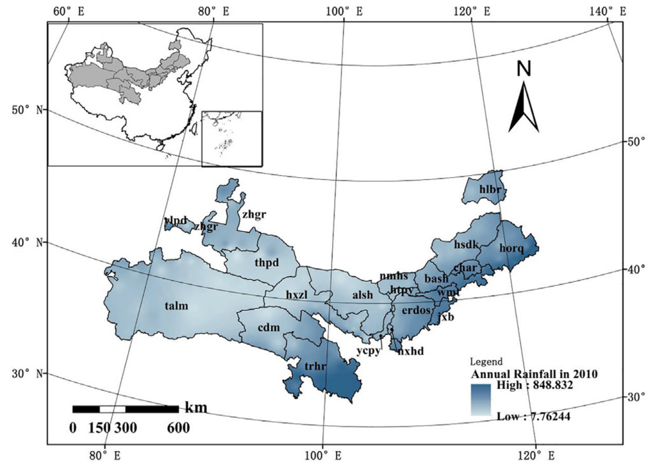

Fig. 1. The location of study area.

To facilitate statistical and comparative analyses, the study area was divided into 20 sub-regions according to the climate characteristics and natural geography (Wang, 2004), including the Hulun Buir grassland (hlbr), Horqin grassland (horq), Hunshandake sandy land (hsdk), Chahar grassland (char), Bashang area (bash), Wumeng Qianshan and Tumote plain (wmt), the northwest area of Shanxi Province (jxb), Erdos grassland (erdos), Ningxia Hedong sandy land (nxhd), Three-River Headwaters region (trhr), Chaidamu basin (cdm), Alashan plateau (alsh), Hetao plain (htpy), Hexi Corridor (hxzl), Houshan region in Inner Mongolia (nmhs), Tarim basin (talm), Turpan Hami basin (thpd), Yinchuan plain (ycpy), Yili basin (ylpd), and Zhungeer basin (zhgr).

2.2. Data sources

The data used in this study included the Normalized Difference Vegetation Index (NDVI) data, land use data, high-resolution remote sensing images, and other auxiliary data. We obtained the 8-km resolution and 15-day maximum value composite NDVI data from 1981 to 2010 from the GIMMS (Global Inventor Modeling and Mapping Studies) NDVI 3 g dataset, which had been pre-processed by geometric correction and graphics enhancement; the GIMMS is widely used in long-term vegetation and land dynamics monitoring. We adopted 1-km resolution land use maps (1:100,000) from the 1980s and 2010 from the Chinese Academy of Sciences Resource Environmental Data Center. The Landsat TM/ETM images covering the study area came from United States Geological Survey (USGS) and Google Earth. Auxiliary data, such as meteorological and statistical information, were also collected from National Meteorological Information Center and the national and regional Statistic Yearbooks. To facilitate spatial analysis and comparison, all the grid and vector data used in this study were resampled or converted into grid data with an 8-km resolution.

2.3. Methods

2.3.1. Land use and land cover classification

To analyze the impacts of desertification on the regional ESV, the land use and land cover of the study area were classified into two categories: deserts and desertified land, and non-desertified land. According to the land use type, non-desertified land was further divided into farmland, forest, undegraded grassland, built-up land, and water areas. The deserts and desertified land were further divided into regions of low, medium, high, and severe desertification based on the degree of desertification. The NDVI data, land use map, and high-resolution images were used to classify the land