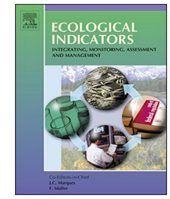
Ecological Indicators 97 (2019) 150–158

Contents lists available at ScienceDirect

Ecological Indicators

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



Assessing the spatial-temporal pattern and evolution of areas sensitive to land desertification in North China

Duanyang Xu[a,*], Xiaogang You[b], Chunlin Xia[b,*]

[a] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] Liaoning Technical University, Fuxin 123000, China

ARTICLE INFO

Keywords:
Land desertification
Sensitivity
Pattern
Evolution
North China

ABSTRACT

Desertification is a global threat to human beings, and effective desertification control requires an interdisciplinary approach to identify the pattern and evolution of sensitive areas. Based on the ESA (Environmental Sensitive Areas) principles and real desertification conditions in North China, the Land Desertification Sensitivity Index (LDSI) was constructed to identify the pattern of areas sensitive to desertification in 1981–2010 as well as their evolution under different climate change scenarios from 2011 to 2030. The results show that regions with low and medium sensitivity to desertification were dominant in North China, which together accounted for 61.93% of the study region. From 1981 to 2010, the average LDSI of North China experienced a decreasing trend, and sensitive areas were mainly distributed in the east of Horqin grassland, Chaidamu basin, the east of Tarim basin, and Zhungeer basin. For the period of 2011–2030, the average LDSI of the whole research region also deceased under both RCP4.5 and RCP8.5 scenarios. However, some regions, e.g., Turpan Hami basin and Zhungeer basin, become more sensitive to desertification. Attention should be paid to desertification control and ecology protection measures in these regions.

1. Introduction

Desertification is a phenomenon of land degradation caused by climate change and human activities in arid and semi-arid regions, which seriously affects and disturbs the survival and sustainable development of human society (UNCCD, 1994). Approximately 6–12 million km^2 of land is suffering desertification, and approximately 1–6% of inhabitants of drylands live in desertified area (World Bank, 2009). In 1990s, the United Nations Convention to Combat Desertification Conference on Desertification focused global attention on combating desertification (UNCCD, 1994). In the 21st century, the Millennium Ecosystem Assessment was launched in 2001 and the 2030 Agenda for Sustainable Development was established by the UN in 2015, and both of these efforts emphasized the importance of linking the ecosystem services provided by deserts and desertified land to human well-being (Millennium Ecosystem Assessment, 2005; UNCCD, 2012; Reed et al., 2015).

Identifying the areas sensitive to land desertification and assessing their spatio-temporal pattern and evolution trend provide an important basis for planning desertification control and ecology protection measures (Sterk et al., 2016). The desertification sensitive areas refer to the locations that exhibit a possibility of desertification due to the presence of various factors. These factors are often associated with terrain conditions, soil and vegetation characteristics, climate, and human drivers (Symeonakis et al., 2016; Karamesouti et al., 2018). The Environmental Sensitivity Area (ESA) method that was originally derived from the Mediterranean Desertification and Land Use Project (MEDALUS) funded by the European Union has been used to assess land degradation or desertification sensitivity by constructing an Environmental Sensitivity Area Index (ESAI) from soil, climate, vegetation, and land management (Kosmas et al., 1999; Salvati and Bajocco, 2011; Salvati and Ferrara, 2015). Due to the benefits of ESA principles, such as simplicity, flexibility, and rapid implementation (Contador et al., 2009; Prăvălie et al., 2017), this method has been applied worldwide to evaluate land degradation and desertification risks (Benabderrahmane and Chenchouni, 2010; Tavares et al., 2015; Symeonakis et al., 2016; Karamesouti et al., 2018). In turn, these applications also provided data that can be used to improve this model (Ladisa et al., 2012). For example, Izzo et al (2013) modified the index in the MEDALUS model and applied it in the Dominican Republic. Jafari and Bakhshandehmehr (2016) fused the index and fuzzy logic to quantify the environmental sensitivity to desertification in central Iran. In order to overcome the limitations of the MEDALUS protocol, Duro et al. (2014) proposed the ESPI index and applied it to sensitive areas in the Sicily region, over

* Corresponding authors.
E-mail addresses: xudy@igsnrr.ac.cn (D. Xu), lngdchxyxcl@163.com (C. Xia).

https://doi.org/10.1016/j.ecolind.2018.10.005
Received 16 July 2018; Received in revised form 20 September 2018; Accepted 3 October 2018
1470-160X/

eight decades of investigation (1921–2000). Salvati and Ferrara (2015) introduced the FIRISK index as a reliable indicator to assess fire risk within the ESAI framework. Prăvălie et al. (2017) assessed the land degradation sensitive areas in southwestern Romania by adjusting the sub-indicators of MEDALUS method based on the local conditions.

China is one of the many countries that have seriously suffered from land desertification. According to the Fifth National Desertification Survey statistics, the area of desertified land in China reached 1,721,200 km^2 in 2014 (State Forestry Administration of China, 2015). The central and local governments have made efforts to combat desertification through various efforts, including the Grain for Green Project, the Beijing and Tianjin Sandstorm Source Treatment Project, the Natural Forest Protection Project, and the “no grazing” statute (Zhang et al., 2012; Xu et al., 2014; Tan and Li, 2015; Xie et al., 2015). However, rapid urbanization, intensive mining and unreasonably afforestation are adding to pressure on desertified land (Cao, 2008; Ge et al., 2016). These trends in conjunction with climate change have led to great desertification risk in North China (Wang et al., 2017). Although previous studies have been conducted to investigate the areas sensitive to land degradation in China via the ESA method (Wang et al., 2014; Sun and Wang, 2015), the method could not be directly used for identifying the areas sensitive to desertification. This is because the ESA indicators and their reference values were derived from MEDALUS and were designed for studying land degradation in the Mediterranean region. Therefore, the ESA method cannot fully reflect the real desertification conditions in North China. Meanwhile, previous studies have largely ignored the prediction of sensitive area change in the future. The prediction of these areas is crucial to support desertification control planning and policy implementation. Therefore, the aims of this paper are to (1) investigate the spatio-temporal pattern of areas sensitive to land desertification in North China from 1981 to 2010 by modifying the ESA method; and (2) to predict the evolution trend of areas sensitive to desertification in North China from 2011 to 2030. The results of this study will hopefully provide a scientific basis to identify key regions for desertification control in China.

2. Materials and methods

2.1. Study area

The desertified areas in China are mainly distributed in the northern regions across the semi-humid, semi-arid, and arid zone, which span 9 provinces (Inner Mongolia, Xinjiang, Qinghai, Ningxia, Gansu, Hebei, Shanxi, Shaanxi, and Sichuan) as well as 222 counties (Wang et al., 2004). The climate characteristics of this region exhibit significant spatial heterogeneity. The average annual precipitation is only 0–450 mm, and it is unevenly distributed in different seasons and regions. Generally, approximately 70–80% of rainfall is concentrated from June to September. The average temperature is approximately 5.7 °C, the average annual sunshine duration is 2807 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 land cover in the study area also exhibit a high level of spatial heterogeneity, including oasis irrigation agriculture, rainfed agriculture, semi-humid and semi-arid steppe grassland, desert grassland, and alpine meadow steppe. The environment and ecological background of the study region is fragile; and the rapid increases in the population, urbanization, and intensive mining activities have created pressure on the land and increased sensitivity to land desertification (Xu and Ding, 2018).

To facilitate statistical and comparative analyses, the study area was divided into 20 sub-regions according to the climate characteristics and natural geography (Wang et al., 2004) (Fig. 1). The sub-regions include the following: 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), the 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 and preprocessing

The data used in this study include climate, soil, vegetation, topography, Normalized Difference Vegetation Index (NDVI), and socio-economic statistics. The monthly average meteorological data from 1981 to 2010, including temperature, precipitation, sunshine duration, and average wind speed, recorded by meteorological stations in the research region were obtained from the National Meteorological Information Center. The monthly average temperature and precipitation data under the Representative Concentration Pathways 4.5 (RCP4.5) and RCP8.5 scenarios from 2011 to 2030 were acquired from the Climate Change Prediction Dataset of China V3.0 provided by the National Climate Center, which was simulated by using RegCM4.0 that one-way nesting the BCC_CSM1.1 and the resolution of this dataset was 0.5° × 0.5°. A 1:1,000,000 soil map, a vegetation map, a Digital Elevation Model (DEM), and a land use map with 1 km × 1 km resolution were obtained from the Resource Environmental Data Center, Chinese Academy of Sciences. The 8-km resolution and 15-day maximum value composite NDVI data from 1981 to 2010 were obtained 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 (Tian et al., 2015; Georganos et al., 2017). The social-economic statistics at the county scale, such as population and livestock number, were collected from the Statistic Yearbooks of the related provinces in North China. To facilitate spatial analysis and comparison, all the raster data and vector data used in this study were resampled or converted into raster data with an 8-km resolution, and the coordinate system was set to Clarke_1866_Albers.

2.3. Methods

2.3.1. Identification of areas sensitive to land desertification

Based on the principles and major indicators of ESA and the actual characters of land desertification in North China, a Land Desertification Sensitivity Index (LDSI) was constructed from four aspects: the Climate Quality Index (CQI), the Soil Quality Index (SQI), the Vegetation Quality Index (VQI), and the Land Management Quality Index (LMQI). The indicators of LDSI are listed in Table 1.

2.3.1.1. Climate quality index. The Climate Quality Index reflects the impact of climate variation on land desertification, and it was modeled via rainfall, slope aspect, an aridity/humidity index, and a wind erosion index (Table 2). Rainfall is the most important factor for vegetation growth and desertification evolution in arid and semi-arid regions (Hickler et al., 2005; Georganos et al., 2017). Slope aspect determines the distribution of solar irradiation and land surface temperatures, which have significant effects on vegetation growth. The aridity/humidity index and the wind erosion index reflect the impacts of the water-heat balance and wind erosion on land desertification, respectively, and smaller values of the aridity/humidity index and the wind erosion index indicate a lower sensitivity to desertification (Wu et al., 2005; Li et al., 2018).

$$Ia = ET0/P \tag{1}$$

$$C = \frac{1}{100}\sum_{i=1}^{12} \bar{u}^3 \left(\frac{ET_{0i} - P_i}{ET_{0i}}\right) d \tag{2}$$

$$ET0 = 0.19(20 + T)^2(1 - r) \tag{3}$$