Catena 147 (2016) 789–796

Contents lists available at ScienceDirect

Catena

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

Quantitative assessment of the relative roles of climate change and human activities in desertification processes on the Qinghai-Tibet Plateau based on net primary productivity

Qing Li, Chunlai Zhang *, Yaping Shen, Wenru Jia, Jiao Li

State Key Laboratory of Earth Surface Processes and Resource Ecology, MOE Engineering Research Center of Desertification and Blown-sand Control, Beijing Normal University, Xinjiekouwai Street 19, Beijing 100875, China

ARTICLE INFO

Article history:
Received 7 March 2016
Received in revised form 12 August 2016
Accepted 5 September 2016
Available online xxxx

Keywords:
Aeolian desertification
Climate change
Human activities
Qinghai-Tibet Plateau

ABSTRACT

Accurately identifying the contributions of climate change and human activities to desertification will support effective strategies for combating desertification. In this study, we employed the changes in net primary productivity (NPP) in areas of aeolian desertification on the Qinghai-Tibet Plateau from 2000 to 2014 to determine the dynamics of desertification. Changes in the potential NPP (PNPP) and the difference between PNPP and actual NPP (ANPP) revealed the relative contributions of climate change and human activities to desertification. We found overall mitigation of desertification during the study period. However, desertification varied both spatially and temporally. Areas with mitigation accounted for 80.1% of the total desertified land; other areas experienced exacerbation. In 67.3% of the area of mitigation, the improvement was attributed to climate change, and especially to increased precipitation. Climate change also accounted for the exacerbation of desertification in 38.0% of the total area in which desertification worsened, largely due to reduced precipitation. Therefore, climate change was the dominant factor for mitigation of desertification, and human activities were the dominant factor for exacerbation of desertification. The dominant factors for mitigation and exacerbation varied spatially. In the central and northeastern Qinghai-Tibet Plateau, climate change was the primary factor for mitigation of desertification and human activities dominated the exacerbation of desertification. In the southern and western Qinghai-Tibet Plateau, the reverse was the case. The ecological protection projects that have been implemented since 2000 in most of the Qinghai-Tibet Plateau have not yet become a dominant factor in controlling desertification processes.

1. Introduction

Desertification is a major type of land degradation occurring around the world, and has become one of the most serious environmental issues (Dregne et al., 1991; UNCED, 1992; Adger et al., 2000; Reynolds and Stafford Smith, 2002; MEA, 2005; Reynolds et al., 2007). Since the 1990s, the environmental and social problems caused by desertification have become one of the key factors preventing sustainable development in the world's arid, semi-arid and sub-humid zones, which account for 41% of the global land area (UNEP, 1991; Williams and Balling, 1996; Reynolds and Stafford Smith, 2002). Climate change and human activities are the driving factors for desertification (UNEP, 1994; Evans and Geerken, 2004; Wessels et al., 2004, 2007; Olsson et al., 2005), but their relative contributions to desertification remain poorly understood (Wang et al., 2006; Xu et al., 2014).

Previous researchers have used correlation analysis (Sun and Li, 2002; Zhang et al., 2003) and principal-components analysis (Dong, 1989; Zhang, 2000) to estimate the contribution of each driving factor. However, these methods suffered from obvious subjectivity in terms of the selection of variables. Recently, some studies have selected vegetation dynamic as an indicator to reveal the impacts of human activities and climate change on desertification (Evans and Geerken, 2004; Wessels et al., 2004, 2007, 2008). Net primary productivity (NPP) provides an objective measure of vegetation cover and plant health, and its variation reveals changes in vegetation growing conditions (Piao et al., 2001). Haberl (1997) first proposed the human appropriation of NPP as a measure of the environmental impacts of human activities. Zika and Erb introduced this approach for the quantitative assessment of the effects of human activities on desertification (Xu et al., 2010). Later studies confirmed that the dynamics of NPP in areas undergoing desertification is a reliable indicator of the exacerbation and mitigation of desertification (Xu et al., 2010, 2014; Zhang et al., 2011; Zhou et al., 2013, 2015). In the present study, we select NPP as the desertification assessment indicator.

Desertification is a serious problem on China's Qinghai-Tibet Plateau. This region is strongly affected by atmospheric circulation patterns and its high altitude, and most areas of the plateau suffer from a cold and dry

---

* Corresponding author.
E-mail address: clzhang@bnu.edu.cn (C. Zhang).

http://dx.doi.org/10.1016/j.catena.2016.09.005

climate, resulting in a fragile ecology that creates favorable conditions for desertification (Li et al., 2001). The monitoring result of aeolian desertified land revealed the area of desertified land accounted for above 10% of the total land area (Li et al., 2001). Serious desertification has therefore hampered socioeconomic development of the Qinghai-Tibet Plateau (Li et al., 2010; Zhang et al., 2009). Due to the fragile ecological environment, the desertification on the plateau was prone to be influenced by the human activities. Overgrazing, excessive cultivation and wood-cutting have caused damage of the natural vegetation, leading to exacerbation of desertification; On the other hand, forbidding grazing, conversion of cropland to grassland and controlling the number of livestock are advantageous for the recovery of the natural vegetation, leading to mitigation of desertification (Li et al., 2010; Lv and Yu, 2011).

In addition, the Qinghai-Tibet Plateau plays a prominent role in the evolution of the Asian monsoon system and acts as a primary water resource for East Asia's major rivers, so desertification on the plateau has greatly affected the ecological environment of China and East Asia (Li et al., 2001). To support the development of strategies to mitigate desertification on the plateau, it is necessary to improve our understanding of the relative contributions of climatic change and human activities to desertification. In the present study, our goal was to provide data on these contributions. To accomplish this goal, we used changes in the actual NPP (ANPP) in desertified land as a quantitative indicator of changes in the desertification status from 2000 to 2014. We also determined the potential NPP (PNPP) based on climate conditions in each part of the study area, and calculated the human-influenced NPP (HNPP) as the difference between PNPP and ANPP. The PNPP and HNPP data were then used to quantify the relative impacts of climatic and anthropogenic factors on desertification on the plateau. Regional differences in the roles of climate change and human activities in desertification, and their changes over time, were also revealed. Through quantifying the roles of climate change and human activities to aeolian desertification on the Qinghai-Tibet plateau, the present study aims to provide useful information to improve our understanding of the key causes of aeolian desertification so that helps the central and local government to figure out effective environmental management measures to combat aeolian desertification.

2. Data and methods

2.1. Study area

The Qinghai-Tibet Plateau is located in southwestern China, where it covers an area of 2,603,431 km^2. The elevation is generally >4000 m (Qiu, 2008). The administrative regions include the Tibet Autonomous Region, Qinghai Province, and parts of the Xinjiang Uygur Autonomous Region and of Gansu, Sichuan, and Yunnan provinces. The plateau is surrounded by great mountain ranges interlaced with valleys and basins. Because of the diverse topography, the climate is very complex. It is generally warm and wet in the southeast and cold and dry in the northwest. Across the region, the annual average temperature ranges from −5.6 °C to 17.6 °C, and the daily temperature difference ranges from 14 °C to 17 °C. The precipitation distribution is uneven. Annual precipitation in the Motuo area, in the southeast, and the Lenghu area, in the northwest, is above 4000 mm and 17.6 mm, respectively. Under the influence of the westerly circulation and the plateau's terrain, annual average wind speed is >3.0 m s^{-1}, with gales (i.e., a wind speed higher than 17 m s^{-1}) occurring >50 days annually (Li et al., 2001).

The Plateau's population density is low, and is mainly concentrated in cities, towns, and river valleys with good natural conditions for crop farming. The average regional population density is 5.0 persons per km^2, but in some areas, it is <1.0 person per km^{-2}. Because of the low temperatures and distribution of precipitation, only about 12,453 km^2 (0.5% of the total area) is suitable for crop farming, mostly in the valleys of the Yarlung Zangbo River, Lancang River, Nujiang River, and Yangtze River in the southeastern plateau and the Yellow River and Huangshui River in the northeast. Animal husbandry is the only agricultural activity in 57 of the total 188 counties, with a total area of grazing land of 1,421,473 km^2 (Zhang et al., 2012; Lv and Yu, 2011), accounting for 40.3% of the total area excessive animal grazing is the major human activity that has exacerbated desertification on the plateau.

2.2. Data sources and processing

Our study period was from 2000 to 2014. Calculation of NPP using the Carnegie-Ames-Stanford Approach (CASA) model (Potter et al., 1993; Field et al., 1995) requires data on the normalized-difference vegetation index (NDVI), land cover data, and meteorological data for the study area. We downloaded the 16-day synthesized, atmospherically corrected maximum NDVI data (MOD13A1) with the spatial resolution of 500 m from NASA's archive and distribution System (https://ladsweb.nascom.nasa.gov/data/). We used the 16-day NDVI data to synthesize monthly NDVI values using the maximum-value compositing method. Land-cover data was derived from a national land-use data downloaded from the China's WestDC site (http://westdc.westgis.ac.cn/). The land-cover data was created mainly based on visual interpretation of Landsat Thematic Mapper images in vector format with a scale of 1:100 thousand and the average interpretation accuracy was 92.9% (Liu et al., 2003). The data was resampled to a spatial resolution of 500 m. The meteorological data were derived from China's Meteorological Data Sharing Service System (http://cdc.nmic.cn/home.do), which includes monthly average temperature and total precipitation recorded at 122 meteorological stations on the plateau, and the total solar radiation recorded at 26 meteorological stations in and around the study area. The spline function interpolation method used polynomial fitting to generate a smooth interpolation curve. It was suitable for the interpolation of meteorological data (Li et al., 2006). So we applied the spline function interpolation method to interpolate the meteorological data to generate monthly raster images with a spatial resolution of 500 m. We applied the Albers equal-area conical projection and WGS-84 datum to all spatial data.

We used visual interpretation of 30-m-resolution Landsat image data from 2000 to obtain the distribution of aeolian desertified land. The interpretation accuracy was better than 95% according to the field verification results with the Kappa coefficient of 94.3%. The data was resampled to a spatial resolution of 500 m and transformed to the same coordinate system as for all spatial data. The results showed that aeolian desertified land on the plateau covered 401,632 km^2 in 2000, accounting for 15.4% of the total area. The area of aeolian desertified land in Tibet autonomous region and Qinghai Province was 205,956 km^2 and 129,434 km^2, respectively. The results were very close to the data derived from Landsat TM images by China's State Forestry Administration in 1999 that was 201,895 km^2 and 119,645 km^2 in Tibet autonomous region and Qinghai Province, respectively (SFAC, 2000). The aeolian desertification was widespread (Fig. 1). Except for the large and concentrated distribution of desertified land in the northern Plateau, most of the desertification was scattered throughout the plateau, but concentrated mostly in the western half. The area of the patches of desertification increased from southeast to northwest on the plateau.

2.3. Calculation of ANPP, PNPP, and HNPP

CASA model was established based on the vegetation mechanism. Although with some weaknesses on the parameter determination and the model calculation (Zhang et al., 2011), it was the most widely used model in recent years since it fully considered the environment conditions and the characteristics of vegetation (Gao et al., 2009). So present study used the CASA model to calculate ANPP (g C m^{-2} yr^{-1}). CASA accounts for the light-use efficiency of vegetation using a model derived from a combination of remote sensing, meteorological data, vegetation types, and soil data (Potter et al., 1993; Field et al., 1995). ANPP is determined based on the absorbed photosynthetically active