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Quantitative assessment of the individual contribution of climate and human factors to desertification in northwest China using net primary productivity as an indicator

Wei Zhou[a], Chengcheng Gang[b], Fuchun Zhou[a], Jianlong Li[b,*], Xiaogang Dong[c], Chengzhang Zhao[c]

[a] Department of Resources and Environment, School of River & Ocean Engineering, Chongqing Jiaotong University, Chongqing 400074, China
[b] School of Life Science, Nanjing University, Hankou Road 22, Nanjing 210093, China
[c] College of Geography and Environment, Northwest Normal University, Lanzhou 730070, China

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ABSTRACT

An accurate quantitative assessment of the relative roles of climate change and human activities in desertification is significant to understand the driving mechanisms deeply and control desertification development. In this study, we selected net primary productivity (NPP) as an indicator to discriminate the relative roles of climate and human factors in desertification during 2001–2010 in northwest China. The potential NPP and the difference between potential and actual NPPs were used to represent the impacts of climate change and human activities on desertification. Desertification expanded on 55.8% of the study area, within which 70.3% of the desertification expansion was caused by human activities compared with only 21.7% induced by climate change. On the contrary, 42.1% of desertification reversion was caused by human activities and 48.4% resulted from climate changes. The NPP variation also could be calculated to assess the relative roles and showed that 69% of NPP decrease was caused by human impacts compared with 15.2% induced by climate change. By contrast, 23.9% of NPP increase was caused by climate change, whereas 54% resulted from human activities. In addition, the relative roles of two factors possessed great spatial heterogeneity in six provinces. We developed three propositions. First, the desertification expansion was dominated by human activities, whereas desertification reversion was dominated by climate change, as typified by Xinjiang, Qinghai, and Gansu. Second, both desertification expansion and reversion were induced by human activities, as typified by the west of Inner Mongolia and Shaanxi. Third, climate change dominated the desertification expansion in Ningxia province.

1. Introduction

The determination of the driving cause of desertification has become the focus of desertification research. A great deal of disagreement about the driving factor of desertification remains (Rasmussen et al., 2001; Reynolds and Stafford Smith, 2002; Wang et al., 2006; Zheng et al., 2006). Many researchers have attributed the desertification in northern China to long-term over-grazing, extensive cutting, and widespread conversion of grassland to cropland (Wang and Zhu, 2003; Yang et al., 2005; Wang et al., 2006). Other studies have found that poor climate conditions, such as drought, severe wind erosion, temperature fluctuation, and winter precipitation, are the primary cause of desertification (Hai et al., 2002; Sun and Li, 2002). Nevertheless, some recent studies have shown that human activities control the desertification reversion (Xu et al., 2010; Wang et al., 2012) in selected study regions of northern China.

Using an optimal quantitative assessment method is actually crucial for assessing the relative role of climate and human factors in desertification (Veron et al., 2006). Quantitative assessment methods in previous studies primarily focus on statistical analysis, including regression models (Zhang et al., 2003), correlation analysis (Chang et al., 2003), and multiple variable analysis technology (Ma et al., 2007). Some studies have selected vegetation dynamic as an indicator to differentiate human-induced desertification from climate change-induced desertification (Evans and Geerken, 2004; Wessels et al., 2007; Xu et al., 2010). Net primary productivity (NPP) is the net amount of solar energy converted to chemical energy through photosynthesis and a sensitive indicator to climatic changes and human

* Corresponding author. Tel.: +86 02583592715.
E-mail address: jianlongli@gmail.com (J. Li).

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impacts (Schimel, 1995). NPP has been adopted as an indicator to discriminate the impacts of climate change from those of human activities on ecosystem (Zheng et al., 2006; Wessels et al., 2008). Some researchers have used human appropriation of net primary production (HANPP) as an indicator to measure the impact of human activities on ecosystem in recent years (Rojstaczer et al., 2001; Haberl et al., 2002). Meanwhile, the relationship between NPP and desertification has been widely studied. The change of NPP has been a potential desertification evaluation indicator (Mouat et al., 1997). Some research based on long-term site observation has found that aboveground NPP is lower in desertified shrub lands than in remnant grassland in Chihuahuan desert of USA (Huenneke et al., 2002). Desertification leads to fragmented ecosystem structure and decreased carbon storage (Asner and Martin, 2004). Therefore, NPP can be a useful and reliable indicator of desertification in long term (Prince et al., 1998; Gonzalez, 2000). In this study, we select NPP as desertification assessment indicator.

China is one of several countries severely affected by desertification. The land desertification of China accounts for 27.3% of the total land area according to the first national survey on desertification land. Approximately 99.6% of this land is distributed in 12 provinces or autonomous regions in north and northwest China (CCICCD, 1996). Northwest China is located in regions sensitive to climate change and human intervention, includes most of China's desert, and is the origin of sandstorm in China (Wang et al., 2004a). A recent survey has shown that over 90% of grassland in north China suffered different degree of degradation and that degradation rate reached 6700 km^2 per year (Yang, 2002). Therefore, a deeper understanding of the driving cause of desertification is fundamental and a key point in desertification control. In this study, NPP was selected as an indicator to evaluate desertification status, potential NPP, and HNPP (the difference between potential NPP and actual NPP) for representing the impacts of climate change and human activities on desertification.

The objectives of this study are to (1) explore the desertification dynamics in northwest China, (2) distinguish the relative roles of climate change and human activities in desertification, and (3) determine the spatial distribution of the two driving factors that induce desertification expansion or reversion and the dominant factor for desertification.

2. Materials and methods

2.1. Study area

Northwest China is located in the innermost center (31°32′N–49°10′N and 73°15′E–111°50′E) of the Eurasian continent. This area covers an area of approximately 3.5 million km^2 and accounts for 36% of China's total land areas. Administratively, this area includes Xinjiang Uygur autonomous region, Qinghai province, Gansu province, Shaanxi province, Ningxia Hui autonomous region, and the west of Inner Mongolia autonomous region (IM). Climate belongs to arid and semi-arid, except Qinghai, which is characterized with rich solar–thermal resources, dry and rainless climate, strong evaporation, as well as high temperature between day and night. The high mountains with high precipitation, such as Altai, Tianshan, Kunlun, and Qilian mountains, block atmosphere circulation and create vast desert basin in rain shadow, such as Tarim, Junggar, and Qaidam basins (Shi et al., 2007). Northwest China also includes most of China's desert and Gobi. The regional difference of landform and climate is obvious, and vegetation shows dramatic horizontal and vertical zonalities.

Desertification is a process that operates principally in arid, semi-arid, and sub-humid areas and involves excessive pressure of human use, changes in land use, or changes in natural process (Mouat et al., 1997). This process leads to a general decrease in productivity and soil erosion (both by wind and water), salinization and alkalization of irrigated lands, or dryland salting. The excessive loss of soil nutrients and sometimes the depletion of soil seed bank affect the capacity of vegetation to recover and constitute the principal mechanism of irreversible damage to the environment (Squires, 2010). The impact of overgrazing on grassland also leads to land degradation (Li, 2009). In China, desertification has usually occurred in Gobi and deserts with mobile sand. The resulting adverse changes have been defined as land degradation characterized by wind erosion. Although other land degradation processes, such as water erosion and salinization, have also occurred in arid and semi-arid areas in China, their areas account for no more than 16% of the total areas of degraded land (SFAC, 2005); therefore, "sandy" desertification is the dominant process responsible for land degradation in China.

Under global warming and human intervention, northwest China's land desertification is becoming serious, and dust and sandstorms (DSSs) occur frequently and become severe. Therefore, quantitative assessment of desertification is essential to control and combat desertification and benefits the program to control DSS.

In this study, we excluded the hyper-arid regions in northwest of China based on the definition of desertification (UNCCD, 1994). The hyper-arid region and study area are shown in Fig. 1.

2.2. Data source and processing

Remote sensing (normalized difference vegetation index (NDVI) and land cover data), meteorological, and geographical data were obtained to estimate NPP based on Carnegie–Ames–Stanford approach (CASA) model. The 500 m 16-day moderate resolution imaging spectroradiometer NDVI data and global land cover product (MCD12Q1) were derived from http://ladsweb.nascom.nasa.gov/data/search.html. Maximum-value compositing procedure was used to merge the 16-day NDVI data and generate monthly NDVI. These remote sensing data were reprojected from the original integerized sinusoidal projection to an Albers equal area and WGS-84 datum by using ArcGIS V9.3 (ESRI, California, USA).

Meteorological data were obtained from China meteorological science data-sharing service system. The data include the monthly average temperature and total precipitation recorded by 210 meteorological stations, as well as the total solar radiation recorded by 45 stations in and around northwest China. Ordinary Kriging interpolation was performed to interpolate the meteorological data intended for producing raster images with 500 m spatial resolution. These monthly meteorological data were used to drive CASA model.

The meteorological data required for Thornthwaite memorial model are annual average temperature and total precipitation. These annual data were calculated from monthly meteorological data. Raster meteorological data were also extracted using the vector boundary of the study area. The images with the same spatial resolution and coordinate system as those used in CASA model were used for remote sensing.

2.3. Field measurement of NPP

To validate the accuracy of CASA model, field-measured NPP was collected. For forest, 20 forest NPP databases created by a previous research (Luo, 1996) were directly used in this study because these datasets have been widely used to validate forest NPP (Pan et al., 2004; Peng et al., 2009).

We also sampled 43 sites about shrub and grassland across northwest China from April to August of 2008 and 2009. At each