Ecological Indicators 93 (2018) 91–99

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Quantifying the relative impacts of climate and human activities on vegetation changes at the regional scale

Rui Liu[a], Linlin Xiao[a,*], Zhe Liu[b], Jicai Dai[a]

[a] School of Geography and Tourism, Chongqing Normal University, Chongqing 401331, China
[b] Shaanxi Provincial Land Engineering Construction Group, Xi'an 710075, China

ARTICLE INFO

Keywords:
Relative contribution rate
Human activities
Climate factor
Vegetation variation

ABSTRACT

Understanding human and climate-induced vegetation changes could benefit regional ecological management. In this paper, a framework was established to quantify the relative contribution rates of human and climate factors to vegetation changes in Chongqing, China, from 2000 to 2015. MODIS NDVI time series data were collected, and land use data were produced using Landsat TM/OLI images. A combined analysis of land use and vegetation changes was conducted, and the residual trends method (RESTREND) was explored in the framework. The results showed that Chongqing experienced a significant vegetation increase from 2000 to 2015. The relative contribution rates of human activities and climate to the vegetation changes were 90.96% and 9.04%, respectively. These results indicate that human activities had a dominant role in vegetation restoration in Chongqing in 2000–2015. Throughout the study period, extensive land use changes occurred in Chongqing. During the study period, persistent forested land, farmland-forested land (a land use conversion type), persistent farmland, and grassland-forested land were the four most important land use (changed and unchanged) types attributed to the growing season NDVI (GSN) increases in Chongqing from 2000 to 2015. The contributions of these four land use types were 45.03%, 21.19%, 16.79% and 12.60%, respectively. The farmland-forested land was characterized as the most effective land use conversion type for vegetation restoration. The proposed framework allows for human and climate-induced vegetation changes to be quantitatively distinguished at the regional scale and provides the contribution rates of each changed and unchanged land use type. The framework is expected to be useful for regional ecological management and research.

1. Introduction

Both natural factors (e.g., temperature and precipitation) and human activities (e.g., deforestation and ecological restoration engineering) significantly impact variation in the world's vegetation (Huang et al., 2016; Sun et al., 2013). Due to growing populations and economies, human activities are becoming the dominant factors driving vegetation changes in much of the world. Research on the human dimensions of environmental change is of extreme importance to ensure a sustainable relationship between humans and the environment. Therefore, it is necessary to distinguish between human and climate-induced vegetation changes at the regional scale (Li et al., 2015; Ellis and Ramankutty, 2008; Seabrook et al., 2011).

Previous studies have applied climatic, historical and archaeological archives and data from various sites to address the above issue over long time series (Azuara et al., 2015). For example, Le'zine et al. (2013) discussed the relationship between human settlement patterns and vegetation changes during the Holocene along the northwestern margin of the Central African rainforest. These types of studies lack integration and systematization of data sources, and in situ observations are costly, time-consuming and spatially limited (Li et al., 2006).

Over the past few decades, the development of remote sensing has made satellite-based imagery (e.g., MODIS and Landsat) one of the most important data sources for monitoring vegetation dynamics at large scales (Pettorelli et al., 2005). The normalized difference vegetation index (NDVI), one of the most important remote sensing products based on the red and near-infrared portions of the electromagnetic spectrum, is highly efficient at monitoring the variability in vegetation at both global and regional scales (Huete et al., 2002; Pinzon et al., 2014). Using a remote sensing product, Liu et al. (2012) used an empirical orthogonal function (EOF) combined with a Mann-Kendall test to analyse the global change in vegetation biomass and attributed the changes to environmental and human drivers. The method was limited to the interpretability of the vegetation variation and could not quantitatively distinguish between the contributions of the environment and humans.

* Corresponding author.
E-mail address: xiaoll@cqnu.edu.cn (L. Xiao).

https://doi.org/10.1016/j.ecolind.2018.04.047
Received 15 July 2017; Received in revised form 4 February 2018; Accepted 18 April 2018
1470-160X/

The residual trends method (RESTREND) allows for the separation of human activities from climate influences on vegetation by developing an NDVI climate model. The method treats the residuals between the observed and predicted NDVI (using climate variables and the NDVI climate model) as the human influence on vegetation variation. The analysis of the temporal trends in residuals to monitor human-induced vegetation trends has been commonly used in many studies (Tong et al., 2017; Wessels et al., 2007). Clearly, the RESTREND yields qualitative results. However, it is believed that the method of separating human activities from climatic influences of the RESTREND has promise to further improve quantitative research in this field.

There have also been attempts to probe the relationship between human/climate factors and vegetation variation using regression analysis methods (Jiang et al., 2017). For example, Feng et al. (2015) used a pooled regression model to calculate the relative contribution of climate and human activities to NDVI changes in China from 1983 to 2012. The results showed that socioeconomic factors and climate factors accounted for 53.4% and 46.6% of the NDVI variation, respectively. Nevertheless, regression analyses have deficiencies. Human activities (e.g., population, gross domestic product, length of roads, afforestation area, livestock number) can be very complicated and diverse (Xiao et al., 2017). It is impossible for regression equation to consider all human factors and their complex interaction effects. In addition, limited by the accessibility of human factors, regression analyses are conducted only at the administrative unit level (for example, the county level). This coarse resolution might lead to the loss of detailed spatial information inside the administrative unit.

Given this background, this study intends to determine the relative contributions of human and climate factors to vegetation changes at the regional scale by developing a new framework in conjunction with RESTREND and land use and land cover change (LUCC) theory. The new framework is designed to derive information at the pixel-level, which completely removes the limitation of administrative units. In addition, with the RESTREND introduced, various human activities and their complex interaction effects produce no uncertainty in our new framework. Therefore, the framework could resolve the shortcomings of the regression analysis methods previously mentioned. This paper is organized into six sections. Following the introduction, we provide a brief background on the relationship between LUCC and the NDVI change and the implementation of large-scale conservation programs in China. The third section introduces the study area and datasets. The fourth section introduces the method or process of constructing the framework. The fifth section provides the main results and the discussion. The final section is the conclusion that summarizes our main findings and provides directions for future research.

2. Background

2.1. Land use change and vegetation change

Land use refers to management and modification of the natural environment or wilderness areas into a built environment, such as settlements and semi-natural habitats including arable fields, pastures, and managed forests (Wright et al., 2012). Depending on human intentions and purposes, each land use type has a different management style and utilization intensity (e.g., frequency of annual mowing, fertilization, irrigation, and number of grazing and animals), thus producing various vegetation cover fractions and specific vegetation units assigned to each type of land use (Tasser and Tappeiner, 2002). Numerous studies have demons trated that land use changes (e.g., deforestation/forestation, desertification and construction expansion) can be characterized by the distinct, abrupt anthropogenic impacts on the land surface that cause fundamental changes to the vegetation (Runnstrom, 2003; Lambin and Meyfroidt, 2011; Hitztaler and Bergen, 2013; Hu et al., 2015; Li et al., 2015). These changes are rarely reversible because of continued human management after the intended land use change. When lands are abandoned, natural succession starts immediately, and the vegetation cover conditions could be determined by the time since abandonment (Tasser and Tappeiner, 2002). Although climate change can impact vegetation cover, during a relatively short period of time (no more than twenty years) without significant variations in climate, it is believed that vegetation changes in the areas experiencing land use changes (except for land abandonment) can be mostly attributed to human impacts.

2.2. Ecological restoration projects in China

With the largest population in the world, China has experienced substantial ecological destruction. Several decades ago, tree felling and biomass fuel collection were the most popular resource utilization models in rural areas (Shi et al., 2000). Over the past two decades, China has been implementing significant large-scale ecological restoration projects (ERPs) (Wang et al., 2016), including planting on previously barren or abandoned wastelands, reforestation, conversion of cropland to forest and grassland and closed forest projects (Yin, 2010, Li et al., 2013). The policy-driven characteristics of ERPs have garnered substantial support at the national level. Many studies have been conducted to explore the land use changes resulting from these ERPs and to evaluate the effectiveness of these land use changes as part of in the ecological restoration at the local and regional scales (Cao et al., 2011; Zhang et al., 2012). Among the ERPs, the closed forest project, which has been widely implemented in China, has a special characteristic. Closed forest refers to the conservation of a forest by prohibiting any anthropic disturbance, not to the conversion of the land use type. The greatest contribution of the closed forest projects to vegetation recovery can be explained by the decrease in anthropic disturbances. In comparison to land use conversion, we believe that a decrease in anthropogenic disturbance in the forest creates another way for humans to drive vegetation change.

3. Study area and datasets

3.1. Study area

Chongqing is the largest city in China, with a total area of approximately 82403 km^2. It is located in southwest China, upstream of the Three Gorges Dam, and encompasses the upper Yangtze River area (between the north latitude 28°10′-32°13′ and the east longitude 105°11′-110°11′). Because of this special geographical location, the ecological issues of Chongqing are critical to the regions surrounding the Yangtze River and the Three Gorges Dam. Since 1997, when the area was designed as China's fourth direct-controlled municipality (the other three are Beijing, Shanghai and Tianjin), Chongqing has experienced very rapid economic development. By 2015, there were 38 districts within the city, and the combined urban built-up area was approximately 650 km^2; the population was 33.17 million, 30.17 million of which were permanent residents, with 60.94% of the permanent residents living in urban areas; and the GDP per capita was 52,094CNY. However, with the rapid economic development, ecological and environmental pressures also significantly increased; e.g., energy consumption increased by 218% during the period of 1999–2010 (Yu et al., 2017). The ERPs mentioned in Section 2.2 have also been widely implemented in Chongqing, which greatly contributed to Chongqing's vegetation recovery in recent years. It is to be observed that, in addition to the national-level ERPs, Chongqing has made and enforced several other provincial-level ERPs during the past two decades, such as the eco-agricultural engineering program, forest Chongqing strategy and natural forest protection project (Fan, 2001).