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What drives the vegetation restoration in Yangtze River basin, China: Climate change or anthropogenic factors?

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ABSTRACT

Knowledge of the vegetation dynamics is critical for addressing the potential challenges and threats facing the land surface ecosystems. Various climatic and anthropogenic factors such as temperature, precipitation, ecological engineering, and population density can affect the vegetation conditions. Yet how vegetation in the Yangtze River basin (YRB) responses to climate change and human activities is not well established. We investigate the spatiotemporal variations of vegetation coverage using Normal Difference Vegetation Index (NDVI) during 1982–2015, and distinguish the effects of climatic and anthropogenic factors on vegetation dynamics. The results show that the growing-season NDVI (GSN) has increased by 0.09% during the 34-year period, the changes indicated a significant upward trend of vegetation with annual change rates of 0.09% GSN $year^{-1}$ during 1982–2015.especially after 1994, the vegetation coverage has significantly increased. Temperature is a controlling factor determining the vegetation greenness in YRB, and the response of vegetation to precipitation is relatively lower because of the abundant water. Meanwhile, land use changes caused by ecological restoration project is the major driving factor for improving vegetation conditions in YRB, and the spatial distributions between human-induced GSN increasing trends and areas with increased forest have a strong consistency in the north of YRB. High effectiveness of ecological restoration projects are closely related to the combined effects of topography, climate and human management. The areas in northern part of Hubei and Sichuan are characterized by suitable climate and moderate elevation, leading to a high effectiveness for vegetation restoration. For the Hengduan Mountain area with complex terrain and lower precipitation added with poor traffic accessibility, low or even no effectiveness of project implementations can be observed. Furthermore, the large-scale migration and movement of the labor force in YRB relieve the environmental pressures and improve the vegetation conditions for the region of emigration.

1. Introduction

Vegetation dynamics have been considered essential in global changes of terrestrial ecosystems (Arora, 2008; Eugster et al., 2010; Walther et al., 2002). As the link between the land and atmosphere, vegetation plays an important role in mirroring and characterizing the Earth's surface energy exchange, carbon cycle, soil ecosystems and regional human activities (Tong et al., 2016; Suzuki et al., 2007). Vegetation dynamics is a complex and long process, and it is influenced by many factors such as climatic change, land-use change, ecological engineering, and urbanization in different regions (Yu and Hu, 2013; Piao et al., 2003; Wu et al., 2014; Yao et al., 2017). Satellite imagery is one of the important data sources to monitor large-scale vegetation dynamics, which has become a widely used tool in the field of ecological protection and global climate change (Nemani et al., 2003; Pettorelli et al., 2005). The satellite-based normalized difference vegetation index (NDVI), based on the reflectance difference of red and near-infrared spectrum, has been considered to be effective in sensing trends in green vegetation and detecting inter-annual variation of vegetation coverage at regional, continental and global scales. (Pinzon and Tucker, 2014; Tüshaus et al., 2014; Guo and Lei, 2013). Recently, many studies reveal that vegetation activities have increased in the northern mid–high latitudes and the vegetation growing season has prolonged, and found that vegetation stability is changing with the external environment (Myneni et al., 1997; Zhou et al., 2009). In the context of global warming and sustainable development, the study of vegetation dynamic and its driving factors is emerging as a research focus worldwide.

Concerning the relationship between vegetation growth and climate variables, it has been detected that NDVI showed dramatic spatial variations in response to climate changes (Gong and Shi, 2003).

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Temperature has a marked positive influence on vegetation coverage in China, which has been the restrictive factor for vegetation growth throughout the whole country (Song and Ma, 2011; Yu and Hu, 2013). However, the relationship between precipitation and vegetation growth is characterized by the geographical heterogeneity. Vegetation coverage is positively correlated with precipitation in most dry areas whereas in humid areas, there was a negative correlation between vegetation conditions and heavy rainfall (Wang et al., 2010; Xu et al., 2014).

In addition to climate change, human activity is another key factor influencing the growth of vegetation. Along with rapid urbanization and population growth, the land use types have undergone great changes, a series of ecological problems occurred, including desertification, soil erosion, and land degradation in arid areas of Northern China (Liu and Diamond, 2005; Zhang et al., 2016). Furthermore, the impact of major Water Conservancy Projects on vegetation coverage should not be neglected, for example, the impoundment of the Three Gorges Project resulted in the expansion of non-vegetation coverage in the upper reaches, and the reconstruction of towns in the reservoir area led to the reduction of forest land and grassland (Han et al., 2013; Wang et al., 2008). In the context of global sustainable development strategy, the Chinese government has invested heavily in human resources and financial resources to improve the vegetation coverage and ecosystem conditions. Especially since the middle of 1990s, a string of large-scale ecological restoration programs such as Grain for Green Project and Yangtze River Basin Shelterbelt Construction Project have been launched, covering 25 provinces in central and southern China (Huang et al., 2013; Jia et al., 2014; Tian et al., 2015a,b). Meanwhile, with the forestation of sloping land and degraded farmland, a large number of rural labor forces have become superfluous in local demand, and the migration of labor to big cities has occurred. In areas with fragile ecological environment, the implementation of the eco-immigration program also has a profound effect on the ecological restoration (Wang et al., 2015). These kinds of movement have broken the original population structure, which in turn have affected the vegetation dynamics (Gesest et al., 2010).

Studies have found a significant increase in vegetation coverage in most parts of China using long-term NDVI data. However, most research concerning vegetation growth have focused on the combined effects of climate change and human activity on inter-annual NDVI trends (Cao et al., 2006; Evans and Geerken, 2004; Zhang et al., 2014), and the influences of human activities on vegetation coverage remain blurry and have not been discussed precisely. Despite great efforts have been made to investigate the responses of vegetation variations to climatic change, limited effort has targeted separating the effects of human-induced factors and climate variations on vegetation conditions. In addition, time-series analysis based on short periods often fails to meet the requirements of dynamic changes of vegetation coverage before and after the implementation of the afforestation project and population migration.

In order to separate the impacts between human activities and climate on vegetation dynamic, we will use long-term Earth observation (EO) data-sets to establish a NDVI-climate model, detect the residuals between observed and predicted values of vegetation trends (Evans and Geerken, 2004; Li et al., 2012; Wessels et al., 2007). Many researchers have recognized that it is unreasonable to use full time series data to develop NDVI-climate models without taking into account existing human impacts (Horion et al., 2016). Here, we introduce a turning point, and establish the model in a reference period with little artificial interference to predict a period of vegetation that should be strongly influenced by human activities (especially afforestation projects and population migration) (Cao et al., 2006; Tong et al., 2017).

YRB plays an important role in maintaining the ecological balance and security of the adjacent area and even the whole country, China. Due to the implementation of ecological engineering, population migration and climate change, the YRB has undergone major changes in environment and landscape. This study centered on vegetation dynamics and its responses to climatic variables and human activities (especially afforestation and population migration) in the YRB. The growing-season NDVI (GSN) was selected as an effective indicator for monitoring vegetation conditions (Fensholt and Proud, 2012; Tian et al., 2015a,b).

The purposes of this study are: (1) to examine the vegetation dynamics and their relationships with climatic factors in YRB, (2) to separate the influences of climate change and human-induced factors on vegetation variations, (3) to relate the human-induced vegetation trends to the ecological restoration programs and population dynamics. Our results will contribute to a better understanding of the variation characteristics and vegetation patterns under the impacts of climate change and human activities, and promote the implementation and management of ecological reconstruction programs.

2. Data and materials

2.1. Study area

The YRB (24°30′–35°45′N and 90°33′–122°25′E) originates from the east of Qinghai-Tibet Plateau, traverses three economic zones in eastern, central and western of China, and crosses 19 provinces of the whole country (Fig. 1). It covers an area of approximately

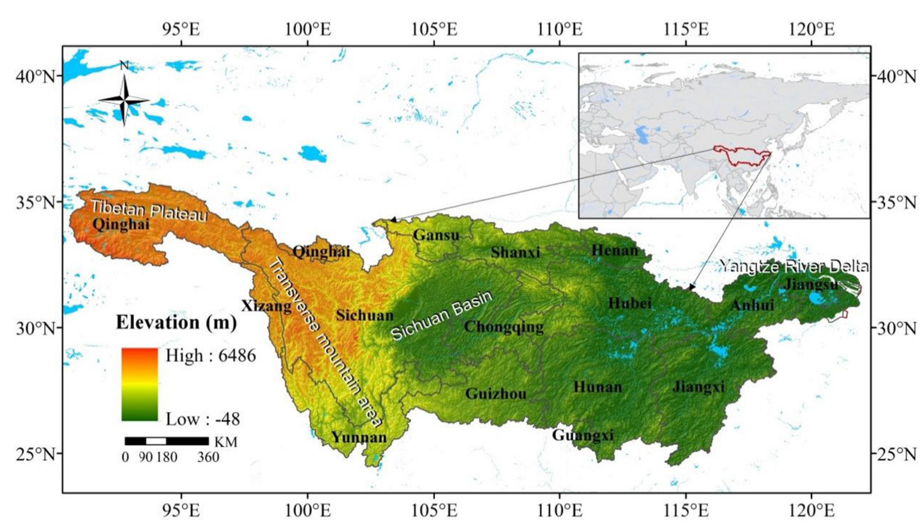

Fig. 1. Topographical map of the Yangtze River basin.