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Original Articles

Vegetation changes in the Three-River Headwaters Region of the Tibetan Plateau of China

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ABSTRACT

The Three-River Headwaters Region (TRHR), located in the hinterland of the Tibetan Plateau, is a key ecological region of China for its abundant natural resources and crucial ecological functions. In recent decades, severe vegetation degradation is observed due to its fragile ecosystems, global climate change and frequent human disturbance. To restrain the further degradation, the Chinese government initiated an ecological conservation project of TRHR in 2005 with a total investment of around 1 billion USD. Here, the vegetation changes during 2000–2015 as well as the effects of the ecological conservation project were investigated using Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) time series and a generic approach for vegetation trend analysis, Detecting Breakpoints and Estimating Segments in Trend (DBEST). The results show that the vegetation of TRHR underwent an overall recovery with NDVI trend from around 0.24 in 2000 to 0.26 in 2015. The project was proved to have a positive but insignificant effect on the vegetation recovery based on the comparison of the vegetation changes inside and outside the reserve from 2005 to 2015. However, TRHR is still at a risk of further degradation because increasing fluctuations in trend were also observed. Significant degradation was found in reserves including Dongzhong, Aangsai, Baizha, Tongtian River and Nianbaoyuze. It is suggested that long-term vegetation and ecosystem conservation efforts remain to be continuously conducted particularly in the aforementioned areas. This study provides knowledge for future ecosystem conservation of TRHR, and also enriches the remotely sensed detection of the vegetation changes.

1. Introduction

The Three-River Headwaters Region (TRHR), located in the hinterland of the Tibetan Plateau, is the source region of Yangtze, Yellow and Lancang Rivers. The TRHR has significant conservation and regulation functions of water resources (Shao et al., 2017a). It supplies 25%, 49% and 15% of the total water for the three rivers, respectively (Zhang et al., 2012), and its annual average runoff reaches around 40 billion m^3 (Shao et al., 2017b). Accordingly, the TRHR is termed as the “Chinese Water Tower.” Special location, abundant natural resources and crucial ecological functions make it an important ecological barrier of the Tibetan Plateau in China (Shao et al., 2017a).

However, the TRHR faces severe vegetation degradation (e.g. grassland degradation showed in Fig. S1), soil erosion, desertification, glacier retreat, lake and wetland decline and so on (Liu et al., 2008; Shao et al., 2009; Zhang et al., 2012) because of its fragile ecosystem, climate change and increasing human activities in recent decades. This poses a serious threat to the ecological and economic development both in this area and also its downstream regions. To restrain the further degradation of the TRHR, the Chinese government carried out the ‘The general planning on ecological conservation and restoration in the TRHR reserve in Qinghai Province’ (referred as ‘The Project’ hereafter) in 2005 (PGQP, 2013). The first stage of ‘The Project’ was implemented from 2005 to 2012 with an investment of approximately 1 billion USD, aiming at improving the vegetation cover through conserving grassland, forest and wetland (Shao et al., 2017a). The second stage has started in 2013 and will end in 2020 with a total supposed investment of 2.4 billion USD (PGQP, 2013; Zhao, 2014).

Vegetation is the principal component of the ecosystem of TRHR and covers over 70% of its total area, mainly consisting of grassland, forest, cropland and part of wetland (Xu et al., 2008). It is the most sensitive component to climate change (Parmesan and Yohe, 2003; Sitch et al., 2003) and its changes are closely associated with livestock breeding, deforestation and desertification monitoring and anthropogenic activities (Purevdorj et al., 1998). To this end, the detection of long-term vegetation changes in this area has been attracting considerable attention from the scientific community (Li et al., 2011; Liu et al., 2014; Liu and Shao, 2014; Sun et al., 2016; Zhang et al., 2016),

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and so has the assessment of 'The Project' on vegetation changes (Cai et al., 2015; Jiang and Zhang, 2016; Shao et al., 2017a). Li et al. (2011) analyzed SPOT VEGETATION Normalized Difference Vegetation Index (NDVI) data and found the vegetation in TRHR showed an increasing trend in density from 2001 to 2010. Zhang et al. (2016) estimated the net primary productivity (NPP) of TRHR from 1982 to 2012, and the average NPP exhibited a generally increasing but fluctuated tendency. Cai et al. (2015) used SPOT NDVI-based residual trend as an indicator, and they revealed 'The Project' mitigated the grassland degradation and even reversed it in some areas.

However, the methods used in these studies are mainly linear regression based on least-square fit, which may obscure changes appearing within short duration (de Jong et al., 2012). Accordingly, new tools for analyzing vegetation time series were proposed such as Detecting Breakpoints and Estimating Segments in Trend (DBEST) (Jamali et al., 2015). de Jong et al. (2012) concluded that such new tools for 'automatic detection' is more promising in the analysis of long-term vegetation changes. DBEST accounts for seasonal variation and decomposes time series into trend (low frequency variation), seasonality (variation at or near the seasonal frequency) and remainder. It is flexible since it allows users to completely control either fine details or general features of the trend to be captured.

In this study, we aim at detecting the vegetation changes of TRHR and further assessing the effects of 'The Project' on vegetation changes using DBEST, which to our knowledge is the first application of DBEST in this region. Both generalized long-term trend and fine short-term fluctuations were characterized, which can be hardly implemented by linear methods. This study includes three components: 1) in Section 4.1, vegetation trend of the entire TRHR and the change magnitude for each pixel were analyzed to show the long-term aggregated changes; 2) in Section 4.2, the major vegetation change was detected to reflect the short-term changes probably caused by specific events (e.g. wildfires, flood and earthquake etc.); and 3) in Section 4.3, the effectiveness of 'The Project' on the vegetation recovery was assessed through a comparison of the vegetation changes inside and outside the reserve.

2. Data and study area

2.1. Data

The ten-day MODND1T NDVI product used in this study was downloaded from the Geospatial Data Cloud (http://www.gscloud.cn/). It was calculated from daily Terra-MODIS (Terra-Moderate Resolution Imaging Spectroradiometer) MOD09GA surface reflectance dataset (Vermote et al., 2011) and was aggregated from the ten-day maximum composites in time. It covers the whole China at 500 m spatial resolution. The time span covers from February 2000 to May 2016 except some unavailable records between 2015 and 2016. Thus, a total of 540 NDVI images from the third ten-day of February 2000 to the second ten-day of February 2015 were used.

The land use/cover dataset of China was downloaded from the Chinese Academy of Environmental Science data center (http://www.resdc.cn) (Liu, 1997). This dataset was produced by visually interpreting Landsat TM/ETM images. It covers years of 1990, 1995, 2000, 2005, 2010 and 2015 and its spatial resolution is 1 km. In this study, the map of 2010 was used to provide water boundary to exclude non-vegetation area (please refer to Section 3.2).

2.2. Study area

The TRHR is the source region of Yangtze, Yellow, and Lancang Rivers and thus referred to as the "Chinese Water Tower." It is located in the hinterland of the Tibetan Plateau, Qinghai province, China (Fig. 1). The TRHR has an area of approximately 363,000 km^2, including 16 counties and Tanggulashan Township (Shao et al., 2017b). It is the largest reserve (~ 152,300 km^2) in China with 18 reserve subregions where 'The Project' was implemented (Shao et al., 2017b). As the world's largest alpine wetland ecosystem, the TRHR has rich rivers, lakes, mountain snow and even glaciers to supply water for the downstream regions (Tong et al., 2014). Its annual average runoff is around 40 billion m^3 (Shao et al., 2017b) and incorporates 25%, 49% and 15% of the runoff of Yangtze, Yellow, and Lancang River Basins, respectively (Zhang et al., 2012). The main land cover includes grassland, wetland, forest, crop, desert and other type accounting for 65.37%, 8.40%, 4.71%, 0.25%, 8.57% and 12.70%, respectively. There are 69 species of national protected animals in the TRHR, including 17 level-I and 52 level-II species (PGQP, 2013).

The high elevation, cold and dry climate and intense radiation in TRHR make it an ecologically sensitive region (Jiang and Zhang, 2016; Xu et al., 2011). The climate dries and the elevation increases from southeast to northwest (Tang et al., 2016), resulting in a better climate condition of the southeast. This corresponds well with the tendency of

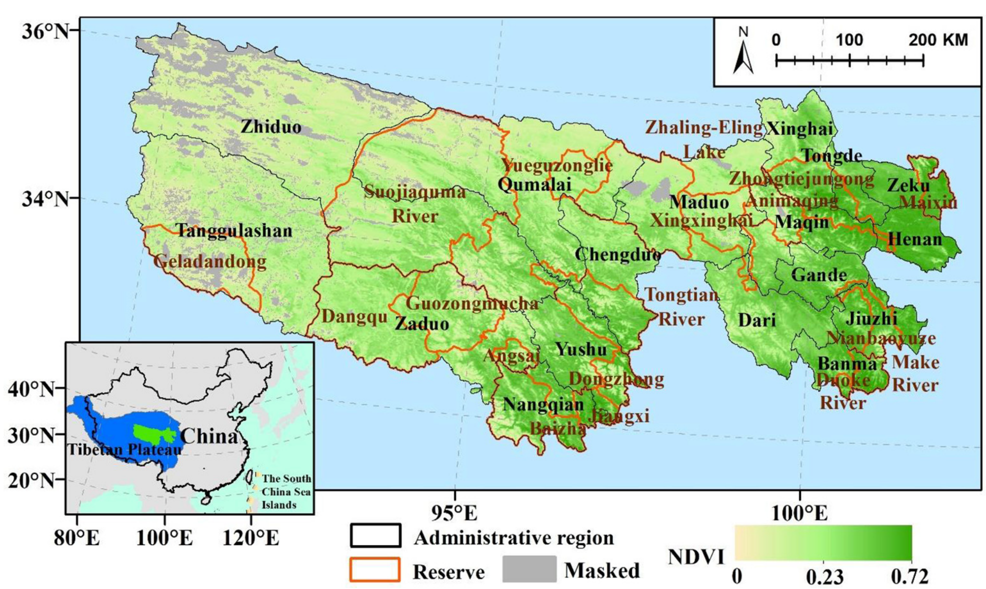

Fig. 1. The location, administrative regions, reserves and the mean NDVI of TRHR. The mean NDVI was calculated by averaging the 540 NDVI images from the third ten-day of February 2000 to the second ten-day of February 2015. The non-vegetation area is masked.