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Original Articles

Anthropogenic contributions dominate trends of vegetation cover change over the farming-pastoral ecotone of northern China

Zhengjia Liu[a,b,*], Yansui Liu[a,b,*], Yurui Li[a,b]

[a] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

Separating anthropogenic contributions from observed vegetation change is helpful for improving our understanding of the effects of human activities on regional ecosystems. In this study, using 1982–2015 GIMMS3g normal difference vegetation index (observed NDVI), monthly climatic variables and land use data, we investigated anthropogenic contributions on vegetation change in the farming-pastoral ecotone of northern China (FPEN). Specifically, given that large-area ecological engineering was practiced since 1999 and large-area land use changes were recorded after 2000, we assumed that human activities only had little impact before 1999. Based on this assumption, we developed a climate-based NDVI model (also termed as TPR-based NDVI model) by using 1982–1999 observed NDVI and assembled monthly precipitation, temperature and solar radiation. Subsequently, the TPR-based NDVI model as well as the residual analysis method were used to separate anthropogenic contributions from observed NDVI in the period of 2000–2015. Results showed that most FPEN performed a greening trend for the period of 1982–2015. Yet a browning trend was also found in central and northern FPEN. The browning trend was largely related to changes of observed NDVI after 2000. Spatial statistics for the best related climatic variable with observed NDVI displayed that temperature, precipitation and solar radiation separately accounted for 42.45%, 31.05% and 26.50% of FPEN, implying their similar importance for vegetation growth in space. Importantly, this study found that anthropogenic contributions dominated trends of observed NDVI over FPEN. Human activities significantly increased NDVI in western and southeastern FPEN ($p < 0.05$), but small decreased NDVI was also observed in central and northeastern FPEN. The findings of this study suggest that applications of anthropogenic ecological engineering and associated conservation measures should be suitable for features of eco-climatic zones.

1. Introduction

Vegetation plays an important role in linking the carbon-water cycle and energy flow between soil and atmosphere (Chen et al., 2015; Fu et al., 2017; Gelfand et al., 2011; Yu et al., 2008). Its dynamics largely affect regional ecological security (Fu et al., 2017; Richardson et al., 2013), especially in fragile eco-climatic zones. Therefore, studies of vegetation change have been hot topics for ecological and remote sensing communities (Jiang et al., 2017; Leroux et al., 2017; Richardson et al., 2013).

The satellite-based normalized difference vegetation index (NDVI) is generally regarded as a proxy of large-area vegetation status given its low cost and easy-to-access features. It is thus widely applied to provide valuable insights into vegetation change (Feng et al., 2016b; Pinzon and Tucker, 2014; Tucker et al., 2005). At the past decades, a lot of studies employed NDVI to explain impacts of changing climate on vegetation growth (Feng et al., 2016b; Fensholt and Rasmussen, 2011; Li et al., 2016; Zhang et al., 2003). Currently, widely-used remote sensing NDVI data mainly include MODIS NDVI, SPOT-VGT NDVI, Advanced Very High Resolution Radiometer (AVHRR) Global Inventory Modeling and Mapping Studies (GIMMS) NDVI and GIMMS3g NDVI (the third generation GIMMS NDVI from AVHRR sensors) in view of their high temporal resolution and robust data quality. Among them, GIMMS3g NDVI is currently the longest time series product, and the data has been widely used to monitor long-term vegetation change at global and regional scales (Pinzon and Tucker, 2014; Wang et al., 2017a; Zhu et al., 2016). In 2016, GIMMS3g group updated their product again. The new generation data cover from July 1981 to December 2015. Importantly,

* Corresponding authors at: Center for Regional Agriculture and Rural Development, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.
E-mail addresses: liuzj@igsnrr.ac.cn (Z. Liu), liuys@igsnrr.ac.cn (Y. Liu).

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the data provide a good chance for investigating long-term vegetation cover change.

Earlier studies mainly pay more attentions to the studies of vegetation growth in response to climate change in view of the sensibility of vegetation to climate change (Cai et al., 2014; Jeong et al., 2009; Peng et al., 2011; Zhang et al., 2013). For example, Zhang et al. (2013) employed GIMMS and SPOT-VGT NDVI to investigate vegetation change in Koshi river basin of the Tibetan Plateau and its responses to climate change for the period of 1982–2011, and reported that climate change likely played the key role in determining trends of vegetation change. Peng et al. (2011) stated that in northern China, warming temperature and enhanced precipitation mainly triggered significantly increased NDVI in growing season before 1990s, but drought induced by warming temperature and reduced precipitation made NDVI decrease after 1990s. Similar to climatic factors, human activities are also responsible for regional vegetation cover change (Abbas et al., 2017; Huang et al., 2016; Jiang et al., 2017; Wang et al., 2017b). As many studies indicated, human activities and climate change are regarded as two major driving factors for vegetation cover change at the regional and global scales (Feng et al., 2016a; Li et al., 2012, 2011). However, different from the way of climatic change impacting vegetation cover, people can usually affect regional vegetation cover by altering land use types or taking some practice of ecological engineering. Recent some studies suggest that anthropogenic contributions in some vulnerable eco-climatic zones can play more important roles in vegetation cover change (Du et al., 2004; Huang et al., 2016; Wang et al., 2015a,b), such as the Tibetan Plateau and the Loess Plateau. Previous these studies improve our understanding of vegetation cover change and its driving factors, but a more comprehensive and clearer picture for quantifying anthropogenic contributions to vegetation cover change is still very imperative.

At present, the residual analysis combined with satellite-based NDVI is regarded as the common and the best effective method to separate the relative effects of climatic change and human activities (Evans and Geerken, 2004). Previous studies usually used precipitation and temperature in growing season to develop climate-based vegetation models and then derive climate-based NDVI (Jiang et al., 2017; Wang et al., 2015a). However, that what time of precipitation and temperature in a year is the best for the estimation of climate-based NDVI is debatable. For example, there is an earlier study implying that monthly climatic variables likely have a better performance in climate-derived NDVI compared to those in growing season or annual scale (Li et al., 2011). Besides, as we know, NDVI can reflect the vegetation growth and it generally possesses a linear correlation with vegetation biomass that is the amount of solar energy converting to chemical energy by plant photosynthesis (Liu et al., 2017b). Therefore, in addition to precipitation and temperature, solar radiation largely plays a key role in vegetation change by affecting the plant photosynthesis. However, the impact of light on vegetation change is rarely considered in climate-based vegetation models. In the residual analysis method, accurately quantifying climatic contributions to actual NDVI is the first importance, because the process subsequently determine the amount of anthropogenic contributions (Evans and Geerken, 2004). Thus, the development of a climate-derived NDVI model with comprehensively considering the interactions of light, temperature and water in a more specific period will be helpful for improving our understanding of anthropogenic contributions to vegetation cover change.

The farming-pastoral ecotone of northern China (FPEN) is one of eight critically fragile ecosystems in China. At the past decades, it suffers from the impacts of both climate change and human activities (Xiang et al., 2014; Zhao et al., 2017). Frequent drought, sandstorms, overgrazing and unsustainable reclamation make FPEN become the most severely degraded zone in China (Liu and Gao, 2002; Xiang et al., 2014). Since 1999, to protect the fragile ecosystems and combat desertification and land degradation, some series ecological engineering, such as the 'Grain for Green' project and the 'Beijing-Tianjin Sandstorm Source Control' project (Feng et al., 2016b; Yang et al., 2015), were practiced in this region. However, there are few studies quantifying anthropogenic contributions (including ecological engineering and other human activities) to vegetation cover change in this region. This limits our understanding for the impact of human activities on vegetation change of FPEN. Excitingly, long-term remote sensing data, climatic variables and the residual analysis method provide a good chance to separate anthropogenic contributions from actual vegetation change.

In this study, the objectives aim (1) to analyze land use change and the trends of vegetation cover change over FPEN; (2) to investigate the impacts of precipitation, temperature and solar radiation on NDVI change, and then develop a climate-derived NDVI model with comprehensively considering the interactions of light, temperature and water; and (3) to separate the anthropogenic contributions to vegetation cover change, and explain the potential mechanism and causes.

2. Data and methods

2.1. Study area

FPEN (34°49′-48°32′N, 100°57′-124°43′E, and area of ~72.5 × 10^4 km^2), locating in the semi-arid and semi-humid transition zone, is regarded as a typical fragile ecological area in China in view of its sensibility for climate change and human activities (Fig. 1). Annual precipitation mainly ranges from 200 mm to 600 mm. Topography of this region increases from northeastern study area (~0 m) to southwestern study area (~2000 m). Croplands and grasslands are the major land use types, accounting for 35.8% and 38.3% of entire study area according to land use data of 2010, respectively.

2.2. Data and processing

Data used in this study included GIMMS3g NDVI, gridded temperature, precipitation, solar radiation, land use and land cover data,

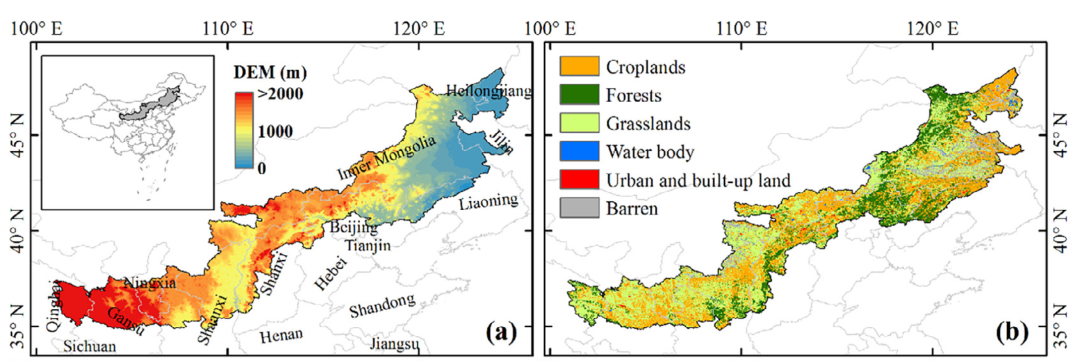

Fig. 1. Location of the farming-pastoral ecotone of northern China (FPEN), and its digital elevation model (DEM), (a) and land use in 2010 (b).