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Original Articles

Is afforestation-induced land use change the main contributor to vegetation dynamics in the semiarid region of North China?

Fangtian Wang[a,b], Pingli An[a,b,*], Can Huang[a,b], Zhe Zhang[a,b], Jinmin Hao[a,b]

[a] College of Land Science and Technology, China Agricultural University, Beijing 100193, China
[b] Key Laboratory of Agricultural Land Quality, Ministry of Land and Resources, China

A R T I C L E I N F O

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A B S T R A C T

Quantitatively analyzing the response of vegetation dynamics to land use change is very important, especially it relates to gaining a better understanding of the effects of ecological restoration projects. Previous studies have focused on the effects of land use change caused by the Grain for Green Project (GGP) on vegetation dynamics, but the effects from other changes in land use have less been explored. Therefore, in order to bridge this gap, Landsat images and MODIS Normalized Difference Vegetation Index (NDVI) data were used to examine how land use had changed from 2000 to 2014 as well as to study its influence on vegetation growth in Ulanqab City, Inner Mongolia, China. For this, four major land use change processes were identified through land use trajectories analysis: the Grain for Green Program (GGP), agricultural intensification, cropland abandonment, and cropland degradation. The GGP caused 36.60% of the total land use change in our study area, while three other processes caused the remaining of 44.40%. Anthropogenic activities significantly influenced vegetation coverage in 10.47% of the research area based on residual trend analysis. Pixels analysis showed 8.72% of the research area experienced a significant increase in vegetation coverage, where 39.53% of this increase was caused by afforestation while 33.25% was attributable to agricultural intensification. However, vegetation degradation was observed in 1.75% of the research area, of which 12.91% was caused by afforestation, an amount that was lower than that caused by the combined effects of the other three practices. Overall, afforestation can effectively increase vegetation coverage, but the overall effects can be undermined by other unstainable land use. However, although agricultural intensification contributed greatly to an increase in vegetation coverage, it also caused severe land degradation. This study demonstrates that ecological restoration projects and regional ecological systems are facing increasing pressure in Ulanqab City caused by an increase in human activity. Managing and maintaining restoration projects sustainably and appropriately in fragile areas will help land managers to achieve better results during vegetation restoration as well as to contribute to sustainable development.

1. Introduction

Anthropogenic land use activities have transformed a large proportion of the planet's land surface and degraded ecological conditions across the globe (Foley et al., 2005). These endeavors create land use change in dryland ecosystems worldwide that expose grassland and woodland to degradation, deforestation, and soil loss (Zika and Erb, 2009). The loss of vegetation in arid and semiarid zones has increased significantly over the last several decades, resulting in land degradation (Landmann and Dubovyk, 2014; Zewdie and Csaplovics, 2016). As grassland is cleared and exposed to severe landscape-level changes caused by extensive human activities, northwestern China is no different and has witnessed a deterioration of natural environment, resulting from the removal of vegetation, soil erosion, desertification, and sandstorms.

Afforestation has been used to restore vegetation coverage as part of a major ecological restoration program to control desertification and environmental deterioration in China (Chen et al., 2007; Le Houerou, 2000; Ma et al., 2013). Pushed into action by a series of serious floods in 1998, the Chinese central government launched some ecological restoration programs in the late 1990s and early 2000s. These included the Grain for Green Program (GGP) and the Grazing Withdrawal Program (GWP) that were introduced in northwest of China with particular emphasis on grassland (Yin et al., 2010). The GGP, also known as the "Sloping Land Conversion Program", is usually explained as a program for "replacing cropping and livestock grazing in fragile areas with trees and grass." To complement the efforts of the GGP, the national government also initiated the GWP, which aimed to conserve grassland by

* Corresponding author.
E-mail address: anpl@cau.edu.cn (P. An).

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banning of grazing and rotational grazing or by converting grazing land to cultivated pasture (Mu et al., 2013).

These projects were applied with different ways in North China and created large changes in land use and land cover (Chen et al., 2008; Zhou et al., 2012). The strong connection between land use and land cover change (LUCC) is a well-recognized agent of environmental change and vegetation is well-known to respond accordingly. As a result, extensive studies have been carried out to evaluate the effectiveness of ecological restoration projects based on land use and vegetation dynamics. Currently, the major fields of study mainly include the monitoring the patterns of land cover change induced by the GGP (Wang et al., 2013; Zhang et al., 2014b; Zhou et al., 2012), analyses of vegetation dynamics (Li et al., 2013; Zhang et al., 2012), and studies of the relative contribution of climate and ecological restoration projects to vegetation restoration (Sun et al., 2015b; Tian et al., 2015; Tong et al., 2017). However, rigorous debate is emerging on the ecological effects of afforestation, some studies have shown that these projects have help to restore vegetation coverage (Chen et al., 2014a; Sun et al., 2015a); while other studies indicate that reforestation has a paradoxical effect that did not always lead to recover in vegetation coverage, even may result in increased ecosystem deterioration (Zhang et al., 2014a). These studies provide a solid background for further study in ecological fragile areas. Nevertheless, the main findings vary depending on different individual basins, time periods and data sources. Notably, numerous studies are focused on the effects of land conversions caused by the GGP on vegetation dynamics, however, current empirical evidence is limited regarding the effects that are caused by other types of land use change. Admittedly, land use change induced by the ecological projects has been largely related to vegetation coverage change, but it cannot be further from the truth. Human-environment systems in northern China have been experiencing unprecedented changes, resulting in drastic land use cover change with noticeable vegetation variations (Ge et al., 2015; Li et al., 2016b). For example, some studies have realized that agricultural production, such as irrigation, has great effects on vegetation growth and ecological environment (Li et al., 2017; Yang et al., 2014). However, current studies have documented specifics regarding land cover change and its influence on vegetation dynamics since the end of the program; these studies have neglected that fact that inferences drawn from other types of land use changes may result in over- or under-estimates of the effects of ecological projects. Because of this gap, we suggest that some previous studies have not paid sufficient attention to the latest changes land use that have occurred with the evolution of natural–human systems. Thus, a need exists to quantify the entire scope of land use change and its influence on vegetation coverage.

With the development of air- and space-borne sensors over the past four decades, remote sensing technology and related methodologies have been adapted to assessing and monitoring LUCC (Du et al., 2002). Optical satellite data, such as data from Advanced Very High Resolution Radiometers, MODIS and Landsat sensors, have been widely used to detect land surface changes and assess regional environmental change in recent years. In particular, Landsat satellite images are ideal for mapping and monitoring land cover because they have a relatively high resolution of 30 m and the longest temporal record of space-based surface observations that extends over 40 years (Roy et al., 2014). Land cover data based on artificial classifications of these satellite images can show the effects of changes in human activities. This type of data can also allow the detection of difference in classifications and are effective for documenting distinct, abrupt anthropogenic impacts on the land surface (Wright et al., 2012). Therefore, we used high spatial and temporal resolution data to detect land use and cover change, displaying the result of human activities on land use. In addition, MODIS NDVI product are very useful in helping researchers to understand continuous and gradual changes such as land degradation through the use of time series analysis (Wright et al., 2012). The present study used MODIS NDVI data to quantify the effects of different human activities. Thus, a combined analysis of land use and cover change with NDVI can help us to both discover the vegetation change of a certain region, and to gain the influent information about LUCC(Li et al., 2017).

To evaluate the effects of afforestation on vegetation dynamics effectively, this study examined the types of land use change that have occurred in Ulanqab City, Inner Mongolia, China and the extent on which LUCC influenced vegetation growth and the changes it provoked. An ecological fragile region located in Ulanqab, Inner Mongolia was chosen for the research region. Our study focused on the following three objectives: 1) to quantify LUCC and identify the main land conversion types from 2000 to 2014. This temporal period was broken into two periods, 2000–2007 and 2007–2014; 2) to analyze temporal and spatial human induced change of vegetation coverage following the inception of the GGP; 3) to combine an analysis of LUCC and human induced NDVI changes in order to quantify the effects of LUCC.

2. Methods

2.1. Study area

The study area, located in Ulanqab City (39°37′–43°28′N, 109°16′–114°49′E), Inner Mongolia, China (Fig. 1), contains six county level administrative units. The landform types listed from north to south include the Mongolia Plateau, the Yin Mountain Range, and Loess Hills. The Yin Mountain Range runs from east to west, dividing the landscape into the Houshan and Qianshan regions. This region's arid and semi-arid climate features an annual average temperature that increases from 3.1 °C in the north to 4.2 °C in the south. Similarly, annual average precipitation increases from 307 mm in the north to 376 mm in the south with more than 70% of the rainfall concentrated in August and September. Ulanqab has suffered severe soil erosion and undergone severe desertification over the last half century as a result of its fragile ecosystems and extensive human activity. The GGP and the GWP were implemented in this region in the early 2000s with the goal of restoring fragile environments.

2.2. Data and pre-processing

2.2.1. Landsat imagery

Landsat (TM/ETM$^+$) images downloaded from USGS (https://glovis.usgs.gov/) with a spatial resolution of 30 m were used to interpret land cover data. Taking vegetation coverage and image quality into account, satellite images were captured in three months (June, July and August) on three years (2000, 2007 and 2014). We chose images with that corresponded to the timing of significant changes in policies. The GGP was implemented nationwide in 2000. The central government declared that no new cropland regions could be approved to join the project after the end of 2006 and the most important task of the GGP shifted from sloping land conversion to barren land afforestation at that time (Wang et al., 2013). Four field surveys from 2012 to 2015 were carried out to ascertain the characteristics of the landscapes in the study area, and training samples were constructed for different landscapes. Based on the ability to classify land use/land cover using Landsat images in the study area, the National Land Use Change Database Hierarchical Classification System was adopted and modified to include classes that can be readily identified on Landsat imagery in our study area (Liu et al., 2005). After the process of geometric correction and FLASSH atmospheric correction, in order to best describe the LULC, we reclassified the LULC patterns into seven types of areas based on local geographical conditions. The areas mapped included dryland, irrigated land, grass, forest, water, urbanized, land and unused land (mainly barren sand). Given that some classes have similar spectral characteristics and a single type of object may have different spectral characteristics, the change detection of different classified maps was then obtained in Arcgis 10.0 after the supervised classification. We applied this kind of change vector to the corresponding Landsat images, and