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Land cover change during a period of extensive landscape restoration in Ningxia Hui Autonomous Region, China

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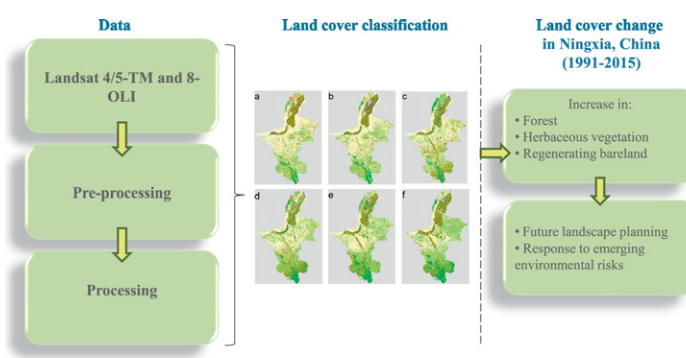
HIGHLIGHTS

- We found an increase in forest, herbaceous vegetation and in regenerating bareland.
- The largest relative change for the period 1991–2015 was observed in the area covered by forest.
- The increase in forest resulted mainly from conversion of cultivated land and herbaceous vegetation.
- Forest growth primarily occurred in the north and south of the province.

GRAPHICAL ABSTRACT



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ABSTRACT

Environmental change has been a topic of great interest over the last century due to its potential impact on ecosystem services that are fundamental for sustainable development and human well-being. Here, we assess and quantify the spatial and temporal variation in land cover in Ningxia Hui Autonomous Region (NHAR), China. With high-resolution (30 m) imagery from Landsat 4/5-TM and 8-OLI for the entire region, land cover maps of the region were created to explore local land cover changes in a spatially explicit way. The results suggest that land cover changes observed in NHAR from 1991 to 2015 reflect the main goals of a national policy implemented there to recover degraded landscapes. Forest, herbaceous vegetation and cultivated land increased by approximately 410,200 ha, 708,600 ha and 164,300 ha, respectively. The largest relative land cover change over the entire study period was the increase in forestland. Forest growth resulted mainly from the conversion of herbaceous vegetation (53.8%) and cultivated land (30.8%). Accurate information on the local patterns of land cover in NHAR may contribute to the future establishment of better landscape policies for ecosystem management and

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Remote sensing
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protection. Spatially explicit information on land cover change may also help decision makers to understand and respond appropriately to emerging environmental risks for the local population.

1. Introduction

Changes in land use and land cover (LULC) are fundamental components of environmental change, and are major determinants of sustainable development and human adaptation to global change (Turner et al., 2007; Turner et al., 1993). Land cover (biophysical cover of the Earth's surface) and land use (description of how humans use the land) are of great significance in maintaining the structure and productivity of ecological systems (Lambin et al., 2001). LULC change influences the climate system through effects on the Earth's surface albedo (the fraction of incident electromagnetic radiation reflected by the land surface) and the exchange of greenhouse gases between the soil and the atmosphere (Foley et al., 2005; Pielke et al., 2002). Thus, land cover change has the potential to impact on climate change at local and regional scales (de Noblet-Ducoudré et al., 2012; Kalnay and Cai, 2003) and also at a global scale (Foley et al., 2005). Some extensive LULC changes may also contribute to diminish or accelerate soil erosion, homogenization of the agricultural landscape and subsequent loss or fragmentation of natural habitats (Blaikie and Brookfield, 2015; Bommarco et al., 2013). These effects have the potential to alter biodiversity (Newbold et al., 2015; Sala et al., 2000) to such an extent that the well-being and vulnerability of humans to social and environmental stressors may be positively or negatively affected (Carpenter et al., 2006).

Human population growth and economic expansion are widely recognised as major anthropogenic drivers of LULC change (Vitousek et al., 1997). Approximately one-third to one-half of the Earth's land surface has already been modified considerably by human activities (Vitousek et al., 1997), and the extent of this transformation may increase to compensate for the growing demand for food and natural resources (Bommarco et al., 2013). In response to the concerns about human capability to adapt to a changing environment, interdisciplinary assessments of LULC status and change have become increasingly important subjects of environmental change research (Verburg et al., 2009).

Since the start of economic reforms in China in 1978, the country has sustained accelerated economic growth and urban expansion. The total population grew from about 980 million people in 1980 to 1.36 billion people in 2013 (National Bureau of Statistics of China, 2014). Resultant social restructuring processes have led to an environmental transformation of unprecedented proportions (Liu and Diamond, 2005). Projects such as the Three-Gorges Dam across the Yangtze River, designed to promote infrastructure and economic development in the country, have been associated with alterations to biodiversity and ecosystem properties in several regions (Xu et al., 2013). To mitigate the adverse impacts of socio-economic and demographic changes, the Chinese government has responded by implementing a series of land reform policies and incentive programs to reduce land degradation and promote sustainable development in rural China (The University of Nottingham, 2010).

The Grain for Green Project (GGP), also called the Sloping Land Conversion Program, implemented since 2002 after a short pilot between 1999 and 2001, is the largest ecosystem service payment project in the country (Liu et al., 2008; Wang et al., 2007). Under the GGP, the government offers farmers annual grain and cash subsidies as well as free seeds or seedlings per area of converted land to reduce soil erosion (Yin and Yin, 2010). The project focuses primarily on the reduction of cropland on steep slopes by promoting three types of land conversions: cropland to forest, cropland to grassland, and sandy land that cannot be used for arable production to forest (The University of Nottingham, 2010; Zhou et al., 2012). The GGP also advocates for prohibition of enclosures for grazing, and sand storm prevention and control (Wang et al., 2007). Some of the immediate ecological benefits of the land restoration program include increased forest coverage, control of soil erosion, and reduced water surface runoff and spread of wind-blown dust (Fan et al., 2015). However, work is still required to explore the additional ecological, climatic and public health consequences that can result from the long-term implementation of the GGP and other similar environmental initiatives (Liu et al., 2008; Pielke, 2005). NHAR is a province located in arid and semi-arid areas across the Loess Plateau and the Yellow River plains which are priority regions for the implementation of the GGP (Liu et al., 2008; The University of Nottingham, 2010). The high local poverty rates, the difficult natural environmental conditions and the over-exploitation of natural resources in NHAR have contributed to the deterioration of the local ecological environment in past decades.

Earth observation (EO) data collected using satellite remote sensing and in situ observations, have been used extensively to characterize and monitor LULC change (Broich et al., 2014; Carreiras et al., 2014; Hamm et al., 2015; Shalaby and Tateishi, 2007; Turner et al., 2007; Yuan et al., 2005). Recently, the wide availability of very fine- (<10 m) and fine- (10 to 100 m) resolution imagery from satellite sensors such as Landsat, QuickBird and IKONOS, have provided new opportunities to represent more accurately LULC at finer spatial resolutions (J. Chen et al., 2015; Hamm et al., 2015; Raj et al., 2013; Sawaya et al., 2003). EO data and geographic information systems (GIS) have been applied in China to guide scientific activities that focus on the assessment and monitoring of the short- and long-term effects of different land use and management practices implemented at various administrative levels (Fan et al., 2015; Liu et al., 2014; Weng, 2002).

This study aims to quantify and describe the spatial and temporal patterns of land cover change in NHAR during a period of extensive landscape restoration. Maps that document accurately the local patterns of land cover change in this province can form the basis for future landscape planning and ecosystem management and protection. This spatially explicit information on land cover change may also help to understand and respond rapidly and effectively to emerging environmental risks such as natural disasters, infectious diseases and food insecurity for the local population.

2. Materials and methods

2.1. Study area

NHAR is a small province located on the upper reaches of the Yellow River in northwest China between latitudes 35°26′ N and 39°30′ N, and between longitudes 104°50′ E and 107°40′ E. NHAR shares borders with the Inner Mongolia Autonomous Region in the north, Gansu Province in the south and west and Shaanxi Province in the east. From north to south, the provincial territory stretches 465 km, and from east to west between 45 km and 250 km, with a total area is 66,400 km^2. NHAR consists of five prefectures that are subsequently subdivided into counties, townships and villages. By the end of 2014, the total population amounted to 6.6 million people of which 53.6% were living in urban areas and 46.4% in rural areas (Li et al., 2008; Statistical Bureau of Ningxia Hui Autonomous Region, 2014).

NHAR lies at ~1000 m above sea level. The territory is geographically diverse and consists of three major natural regions that have distinct agricultural production systems: the northern Yellow River Irrigated District (irrigated agricultural system), the central desertified district (a mix of rainfed and irrigated areas with extensive grazing) and the