Remote Sensing of Environment 195 (2017) 118–129

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Assessment of spatio-temporal changes of smallholder cultivation patterns in the Angolan Miombo belt using segmentation of Landsat time series

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ARTICLE INFO

Article history:
Received 31 August 2016
Received in revised form 4 April 2017
Accepted 12 April 2017
Available online xxxx

Keywords:
Landsat
Time series analysis
LandTrendr
Land use change
Sub-Saharan Africa
Shifting cultivation
Angolan civil war

ABSTRACT

Tropical dry forests provide globally important ecosystem services and host exceptionally high biodiversity. These biomes are currently under immense pressure, particularly for conversion to agriculture, and already experience high global deforestation rates. Miombo forests in Southern Angola are affected by deforestation, fragmentation and degradation, caused mainly by an increasing rural population who follows a traditional farming system of shifting cultivation with slash-and-burn agriculture. After the termination of the civil war in 2002, population growth and resettlements have accelerated the use of woody resources, selective logging and clearing for cultivation purposes and led to an exceedance of sustainability thresholds. Large scale projects are expected to put further pressure on the forests and increase the potential of conflicts regarding land resources and competition with local subsistence farming.

We use an existing time series segmentation tool (LandTrendr) with a time series of Normalized Burn Ratio (NBR) data in combination with adapted temporal metrics to provide information about the dynamics of different cultivation patterns, to gain insight into historical developments and to assess temporal cultivation characteristics. We define cleared areas and cultivation time on a pixel-by-pixel basis providing temporal and spatial information on current and past changes from 1989 to 2013 using data from Landsat 5–8. Overall accuracy for the disturbance detection is 72%. We can follow the effect of armed conflicts on agricultural expansion with a drop in deforestation rate of more than 70% from 12,000 to 4000 ha per year (1994–1998) and subsequently tripling to 12,000 ha per year again after 2002. Deforestation patterns are in accordance with previous multi-temporal studies, although time series segmentation reveals more detailed information on deforestation and cultivation dynamics.

We successfully separate areas of different historic backgrounds and agricultural dynamics, e.g. areas that were severely affected during the civil war, which transition from shifting to semi-permanent and permanent systems. We provide recommendations for the assessment of agricultural dynamics in similar areas where ground data and basic information is missing.

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1. Introduction

The conversion of natural land to agricultural areas has been identified as one of the main challenges of our time (MEA, 2005b) and Southern Africa is expected to be one of the next agricultural intensification hotspots (Gasparri et al., 2015). Yet, in some Southern African areas, cultivation practices are still only rudimentarily developed with ineffective or even no fertilization techniques (Egoh et al., 2012; MEA, 2005a). This is also the case in Angola and mainly due to the civil war, which intermittently lasted for 27 years (1975 to 2002). Beside the large number of casualties, the conflict led to the displacement of rural population, the break-down of the agricultural sector and many impacts on ecosystems and biodiversity, such as the virtual disappearance of most groups of large mammals (Kibble, 2006). The impact and the consequences of

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http://dx.doi.org/10.1016/j.rse.2017.04.012
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the civil war cannot be quantified yet because ground data or reliable statistics on cultivation, socio-economic developments and biodiversity are almost absent especially for rural areas (Brinkman and Alessi, 2009).

After the end of the civil war, the Angolan government invested in the reconstruction of infrastructure, the basic provision of food and currently also in large scale agro-industry (Muzima and Mendy, 2015; World Bank, 2013). Nevertheless, the supply of food, medicine and education is still insufficient especially in rural areas (BTI, 2014). Due to low market access, the rural population relies on natural resources as important livelihood sources, which in some cases also serve as additional cash-income, e.g. by honey, charcoal or bushmeat (Domptail et al., 2013; Egoh et al., 2012). Subsistence agriculture is the main source of alimentary supply. The shifting cultivation system depends on regular forest clearing and fallowing, thus on forest availability to maintain its productivity. Due to ongoing population growth and the rise of competing land uses (urbanization, agro-industrial projects), the region is characterized by increasing land pressure and localized forest depletion, especially around urban centers. Miombo forests cover an area of 2.57 million km^2 stretching from east to west coast in Southern Africa and play an important role in the transport of summer rainfall and humidity from northern rainforests to southern savannas (Leadley et al., 2010; Timberlake et al., 2010). Due to their importance for the global climate system and for local livelihoods and their biological integrity, the Miombo forests of the region have been identified to be one of the next socio-economic and ecological tipping points (Leadley et al., 2010).

The sustainable management of natural resources requires the characterization of different farming systems (Jain et al., 2013). To capture the impact of cultivation on natural resources, especially regarding retrospective developments, both adequate spatial resolution and sufficient temporal resolution are needed. For areas where available information on land use or population dynamics is insufficient, remote sensing provides an objective view on past and current land cover and its change. This spatially explicit information about dynamics in the agricultural sector are of crucial importance to support decision makers regarding future management actions (Atzberger, 2013).

We selected a study area in southern central Angola to analyze agricultural expansion and according cultivation patterns. The region covers the existing land cover diversity with rural and urban areas all being affected during the time of conflict, although to different extents. The Landsat mission data with its spectral setup, a pixel size of 30 m $\times$ 30 m, a repeat cycle of 16 days and its longtime legacy provides the appropriate database to retrospectively address the underlying land use dynamics.

We expand on an established time series segmentation tool (Landtrendr, Kennedy et al., 2010) and apply specific temporal metrics to characterize Landsat time series regarding deforestation and cultivation dynamics. Deforestation detection using LandTrendr has already been successfully applied in predominantly temperate regions (e.g. Anderson et al., 2012; Hudak et al., 2013; Kennedy et al., 2010; Main-Knorn et al., 2013), and to a lesser extent in tropical forests (e.g. Fragal et al., 2016). Regional studies to map dry forest dynamics, particularly in the Miombo belt still restrict to multi temporal Landsat data (e.g. Cabral et al., 2011; Kamusoko et al., 2014; Mayes et al., 2015; Prins and Kikula, 1996). Regarding agricultural developments in sub-Saharan Africa, a limited number of studies concentrate on the medium resolution characterization (e.g. Kiage et al., 2007; Tappan et al., 2000; Thenkabail and Nolte, 1996). Specifically for Angola, spatially explicit studies are almost absent (e.g. Cabral et al., 2011; Schneibel et al., 2016).

Our previous studies using multi-temporal Landsat datasets showed that the rate of annual agricultural expansion doubled between 1989 and 2013 and proved a clear connection to the quality and the location of transportation infrastructure (Schneibel et al., 2013; Schneibel et al., 2016). The analyses also indicated that people generally cut down undisturbed forest instead of reusing fallows. Forest regeneration on fallows is slow and biomass was observed not to recover to the pre-disturbance state after 25 years (Schneibel et al., 2016). However, to determine potential areas of land conflicts due to rising population numbers and the resulting expansion of cultivated land, it is crucial to specifically analyze the annual dynamics in the related smallholder systems and develop conceptual models and methods.

We investigate how the Landsat archive from 1989 to 2014 can contribute to the identification of different smallholder cultivation patterns in dry tropical forest systems. We use a test site in south-central Angola to interpret these related to driving factors between armed conflict to population growth and food security. Specific objectives are to:

- Derive metrics and parameters that are suitable to identify temporal characteristics of rainfed smallholder farming systems.
- Determine the length of cultivation periods according to the farming system.
- Analyze changes in field expansion patterns that reveal different historic and socio-economic backgrounds.
- Provide general recommendations for the assessment of cultivation patterns in similar natural and socio-economic settings with Landsat time series.

2. Study area

The study area is located in south-central Angola and mainly covers parts of the three provinces Cuando Cubango, Bié and Moxico. It includes the municipal administrations Menongue (population of 306,622), Chitembo (pop. 68,581) and Cuchi (pop. 42,899) (INE, 2014). The roads that connect the cities were largely destroyed between 1975 and 2002. Road and bridge reconstruction started after the ceasefire in 2002, whereas continuous pavement of the two main roads started in 2007/2008 and was finished in 2010 for the whole study area (Fig. 1).

Only sparse information about population development, economy or livelihoods is generally available, which is due to the civil war that ravaged in the area, making field work impossible, and to the location in the marginal region of south-east Angola (Brinkman and Alessi, 2009).

We analyzed two subsets in more detail which differ in their historical development and in their current farming systems, i.e. Chitembo and Menongue. While both cities are well connected by one or two paved roads and both are important trading centers for the surrounding population, Menongue has also been an important military center of the People's Movement for the Liberation of Angola (MPLA) during the civil war (Brinkman and Alessi, 2009). Fields in the surroundings were regularly destroyed by the opposing National Union for the Total Independence of Angola (UNITA) forces and people suffered from hunger and insufficient medical supply (Brinkman and Alessi, 2009). Chitembo is located in an area more distant from the former frontlines (Brinkman and Alessi, 2009), where land pressure on forested areas due to agricultural expansion has significantly increased.

2.1. Natural settings

Wet and dry season are highly distinct and the majority of the rainfalls (mean annual rainfall 990 mm) occur during the wet season, i.e. from November to April (Weber, 2013). The study area was chosen because it provides a large urban-wildland interface with intact Miombo forests facing rapidly growing cities with recently improved infrastructure that cross natural woodlands. Large wetlands stretch from north to south with lateral valleys fragmenting the woodlands. These are situated on higher slopes and hilltops. In the wetlands, thick peat layers occur due to the constant interflow from the slopes (Gröngröft et al., 2013).

On the slopes and hilltops of the eastern part, deep sandy Arenosols dominate the soil layer whereas in the west shallow soils on granitic bedrock are found (Gröngröft et al., 2013). The main vegetation unit of the study area is the Miombo forest dominated by *Brachystegia*, *Julbernadia* or *Cryptosepalum* genders. Floodplains are mainly covered

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