Int J Appl Earth Obs Geoinformation 64 (2018) 210–220

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

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

Burned area detection based on Landsat time series in savannas of southern Burkina Faso

Jinxiu Liu[a,*], Janne Heiskanen[a], Eduardo Eiji Maeda[b], Petri K.E. Pellikka[a]

[a] *Department of Geosciences and Geography, P.O. Box 68, FI-00014, University of Helsinki, Finland*
[b] *Department of Environmental Sciences, Fisheries and Environmental Management Group, P.O. Box 65, FI-00014, University of Helsinki, Finland*

A R T I C L E I N F O

Keywords:
Burned area
Landsat time series
Harmonic model
Breakpoint identification
MODIS

A B S T R A C T

West African savannas are subject to regular fires, which have impacts on vegetation structure, biodiversity and carbon balance. An efficient and accurate mapping of burned area associated with seasonal fires can greatly benefit decision making in land management. Since coarse resolution burned area products cannot meet the accuracy needed for fire management and climate modelling at local scales, the medium resolution Landsat data is a promising alternative for local scale studies. In this study, we developed an algorithm for continuous monitoring of annual burned areas using Landsat time series. The algorithm is based on burned pixel detection using harmonic model fitting with Landsat time series and breakpoint identification in the time series data. This approach was tested in a savanna area in southern Burkina Faso using 281 images acquired between October 2000 and April 2016. An overall accuracy of 79.2% was obtained with balanced omission and commission errors. This represents a significant improvement in comparison with MODIS burned area product (67.6%), which had more omission errors than commission errors, indicating underestimation of the total burned area. By observing the spatial distribution of burned areas, we found that the Landsat based method misclassified cropland and cloud shadows as burned areas due to the similar spectral response, and MODIS burned area product omitted small and fragmented burned areas. The proposed algorithm is flexible and robust against decreased data availability caused by clouds and Landsat 7 missing lines, therefore having a high potential for being applied in other landscapes in future studies.

1. Introduction

Fire is recognized as one of the most important ecosystem disturbances, as it contributes to determining vegetation structure, biodiversity and carbon balance (Nielsen and Rasmussen, 1997; Mouillot et al., 2014; Giglio et al., 2010). In the African savanna, fires burn extensive areas annually, and account for a large proportion of the global extent of burned areas (Dwyer et al., 2000). In addition, fires in Africa are driven by factors such as rainfall, tree cover and population density (Archibald et al., 2009). Therefore, accurate mapping of burned areas in savannas is crucial for social and environmental applications (Boschetti et al., 2015).

Remote sensing plays a key role in monitoring burned area at regional and global scales. Due to the high temporal resolution and large spatial coverage, the current burned area products rely on coarse spatial resolution satellite data. A number of global burned area products have been made available, for example, MODIS (Moderate Resolution Imaging Spectroradiometer) burned area product (MCD45A1) based on Terra and Aqua MODIS data at 500 m spatial resolution (Roy et al., 2008), L3JRC burned area product based on SPOT VEGETATION data at 1 km spatial resolution (Tansey et al., 2008), and 1 km Globcarbon burned area product derived from SPOT VEGETATION, ERS2-ATSR2 and ENVISAT AATSR data (Plummer et al., 2006). However, the global burned area products with a coarse spatial resolution fail to detect small and patchy fires, and are not detailed and accurate enough for climate modelling and fire management at regional and local scales (Smith et al., 2007; Roy and Boschetti, 2009; Bastarrika et al., 2011).

Medium spatial resolution imagery provides the much needed improvement in spatial resolution of burned area mapping although global product has not been produced yet. For example, the Landsat satellite image archive stores more than four decades of multispectral observations across the planet, having a high potential for studying fire dynamics. Current methods of burned area detection include manual interpretation and digitalization (Silva et al., 2005), decision tree classification (Kontoes et al., 2009), principal component analysis (Koutsias et al., 2009), artificial neural networks (Maeda et al., 2009), logistic regression (Siljander 2009), thresholding based on post-fire image (Koutsias et al., 2013) or pre-fire and post-fire images (Kontoes

* Corresponding author.
E-mail address: jinxiu.liu@helsinki.fi (J. Liu).

http://dx.doi.org/10.1016/j.jag.2017.09.011
Received 13 February 2017; Received in revised form 14 September 2017; Accepted 21 September 2017
Available online 10 October 2017
0303-2434/

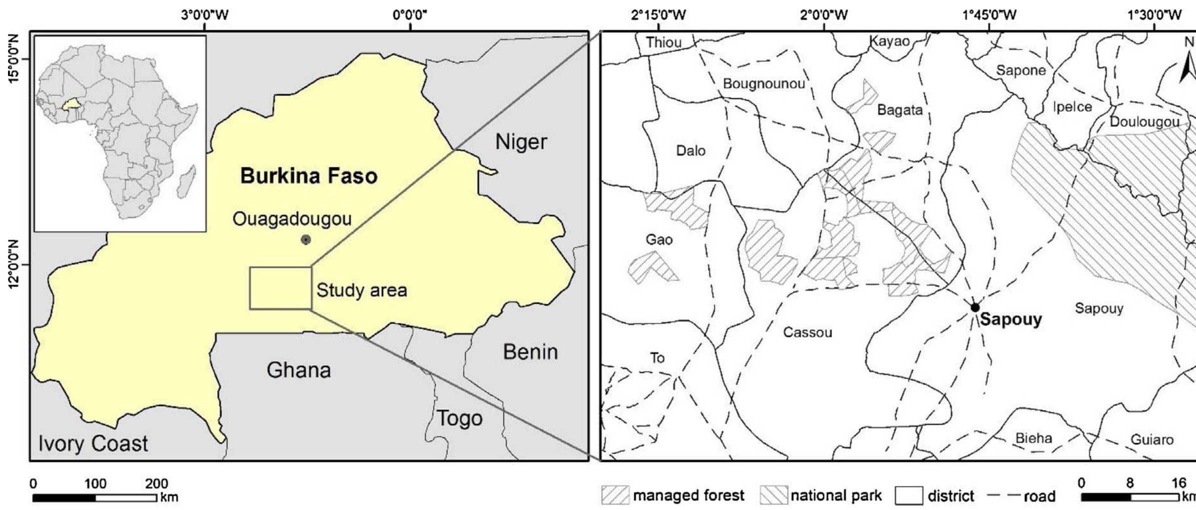

Fig. 1. The location of study area.

et al., 2009; Maeda et al., 2011; Bastarrika et al., 2014), and region growing segmentation (Hardtke et al., 2015). However, most studies have employed spectral differences between pre-fire and post-fire images for burned area mapping and fire severity study. The spectral indices, such as normalized burned ratio (NBR), burned area index (BAI), mid infrared burn index (MIRBI) and global environmental monitoring index (GEMI) have commonly been used to make such comparisons (Chuvieco et al., 2002; Bastarrika et al., 2011, Musyimi et al., 2017; Schepers et al., 2014). Moreover, it was indicated from previous studies that the widely used NBR is less sensitive to burn scars in savanna environments (Goodwin and Collett 2014; Disney et al., 2011), and BAI has been applied effectively for burned area discrimination including savanna area in Africa in previous studies (Chuvieco et al., 2002; Bastarrika et al., 2011; Dempewolf et al., 2007).

However, the approach based on image comparison is hampered by several issues. First, it can be difficult to obtain suitable pre-fire and post-fire images over large areas due to cloud contamination. A manual image selection process is often required to minimize the phenology effect between the image pairs. Second, burned areas demonstrate a spatial and spectral diversity due to the burned vegetation type, fire severity, and the time difference between the image acquisition date and fire date (Stroppiana et al., 2012). During fire seasons, old burn scars are less obvious in comparison to new ones, given the rapid recovery of vegetation. Cloud shadows, water bodies and agricultural areas also exhibit a similar spectral response to burned areas and result in commission errors (Boschetti et al., 2015). Although the image comparison method can achieve good results for a particular region, it can be difficult to apply over large areas. Therefore, more automated approaches for burned area mapping are needed without the limitations of two image comparisons.

With open access to the image archive, Landsat time series have become an important source of medium resolution data for land cover characterization and monitoring. Several time series approaches have been used to identify forest disturbance, clouds and cloud shadows. Zhu and Woodcock (2014b) proposed an algorithm based on harmonic models to automatically remove pixels contaminated by cloud, cloud shadow and snow. Goodwin and Collett (2014) developed an automated method for burned area mapping in Queensland, Australia. The method included detection of outliers caused by burned vegetation, region growing segmentation to map the changed areas, and the classification tree to separate burn scars from other changes. Liu et al. (2016) used seasonal features from an annual Landsat time series for land cover characterization. The harmonic model was used to detect outliers caused by burn scars. However, the use of Landsat time series to monitor long-term burn area dynamics has not been comprehensively studied. Furthermore, burned area detection with medium resolution in a continuous and automatic way has been rarely applied to Landsat time series in savanna area where fires occur frequently.

African savannas are experiencing land cover changes, which must be addressed if burned area detection is applied to long time series. Liu et al. (2016) showed that parameters of the harmonic model vary between land cover types in the savannas of Burkina Faso, particularly between woodlands and cropland. Therefore, the conversion of woodlands to cropland, which is the prevailing land use and land cover change type in the region (Knauer et al., 2017), affects the seasonality of BAI, and for reliable burn scar detection, it is necessary to define periods with stable land cover before model fitting. DeVries et al. (2015) applied an automatic algorithm to track tropical deforestation and degradation in southern Ethiopia based on Landsat normalized difference vegetation index (NDVI) time series data. The algorithm is based on the BFAST method (Verbesselt et al., 2012) and can potentially provide time series breakpoint identification required for burned area detection, although this remains to be tested.

In this study, our objective was to develop and evaluate an algorithm based on harmonic model and time series breakpoint identification to detect annual burned area using Landsat time series. The method was tested in southern Burkina Faso using all available Landsat imagery between 2000 and 2016. Furthermore, the potential of Landsat time series in burned area mapping was compared with MODIS burned area product.

2. Material and methods

2.1. Study area

The study area is located in southern Burkina Faso in the Ziro and Sissili provinces (Fig. 1) and belongs to the West Sudanian savanna ecoregion (Olson et al., 2001). The mean annual precipitation was 827 mm and the mean annual temperature was 27.5 °C in 1950–2000 (Hijmans et al., 2005). Most of the precipitation falls between May and September, the wettest month being August. The driest months are December, January and February. The topography is relatively flat with a mean elevation of 350 m above sea level. The land cover include tropical dry forests and woodlands which are surrounded by agroforestry parklands and agriculture (Liu et al., 2016). The ground layer is dominated by perennial grasses. Forests are partly under community forest management and protection, aiming at providing sustainable fuelwood (Coulibaly-Lingani et al., 2011). The farming system is a mixture of traditional subsistence farming of, for example, sorghum, millet and maize, and cultivation of cash crops, such as cotton, sesame