International Journal of Applied Earth Observation and Geoinformation 34 (2015) 113–121

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Woody vegetation and land cover changes in the Sahel of Mali (1967–2011)

Raphael Spiekermann[a], Martin Brandt[b,*], Cyrus Samimi[b,c]

[a] University of Salzburg, Interfaculty Department of Geoinformatics – Z_GIS, 5020 Salzburg, Austria
[b] University of Bayreuth, Institute of Geography, 95440 Bayreuth, Germany
[c] University of Bayreuth, BayCEER, 95440 Bayreuth, Germany

ARTICLE INFO

Article history:
Received 17 December 2013
Accepted 8 August 2014
Available online 3 September 2014

Keywords:
Sahel
Object based classification
Degradation
Greening
RapidEye
Corona

ABSTRACT

In the past 50 years, the Sahel has experienced significant tree- and land cover changes accelerated by human expansion and prolonged droughts during the 1970s and 1980s. This study uses remote sensing techniques, supplemented by ground-truth data to compare pre-drought woody vegetation and land cover with the situation in 2011. High resolution panchromatic Corona imagery of 1967 and multi-spectral RapidEye imagery of 2011 form the basis of this regional scaled study, which is focused on the Dogon Plateau and the Seno Plain in the Sahel zone of Mali. Object-based feature extraction and classifications are used to analyze the datasets and map land cover and woody vegetation changes over 44 years. Interviews add information about changes in species compositions. Results show a significant increase of cultivated land, a reduction of dense natural vegetation as well as an increase of trees on farmer's fields. Mean woody cover decreased in the plains (−4%) but is stable on the plateau (+1%) although stark spatial discrepancies exist. Species decline and encroachment of degraded land are observed. However, the direction of change is not always negative and a variety of spatial variations are shown. Although the impact of climate is obvious, we demonstrate that anthropogenic activities have been the main drivers of change.

Introduction

The Sahel has been acclaimed as one of the "hot spots" of global environmental change in the last decades. As the 20th century progressed, settlements spread over the Sahel and most forests were cleared for agricultural purposes and an ever growing demand for wood (Brandt et al., 2014a). The degradation of the environmental conditions was accelerated by prolonged droughts in the region during the 1970s and 1980s and an overall decrease in annual precipitation (e.g. L'Hote et al., 2002). Scientists claimed deforestation to be the main causative factor for these climatic changes (Charney et al., 1975). However, several studies have shown that sea surface temperatures largely control Sahelian rainfall fluctuations (e.g. Giannini et al., 2008). Recently, investigators demonstrated again that land cover changes can have an accelerating effect on rainfall variations (e.g. Kucharski et al., 2012; Paeth et al., 2009). These studies put changes in land cover into the focus again and justify the need for detailed investigations on the actual extent of environmental change.

After the droughts in the 1970s and 1980s, the observed loss of woody vegetation cover was often considered as irreversible desertification and large parts of the Sahel were designated as degraded land (e.g. Kandji et al., 2006; Oldeman et al., 1990; Lamprey, 1988). However, almost no evidence of widespread degradation was found (e.g. Niemeijer and Mazzucato, 2002; Tiffen and Mortimore, 2002) and recent findings based on coarse-scaled analyses of satellite time series and ground data show an increase of vegetation greenness over most parts of the Sahel since the mid-1980s (e.g. Dardel et al., 2014; Brandt et al., 2014b; Herrmann et al., 2005; Olsson et al., 2005). However, due to a lack of historical data, it remains largely unclear if this is a return to pre-drought conditions or a transformation of land cover to a new equilibrium state.

High resolution imagery offers the possibility to detect single trees and large shrubs as objects. This has the major advantage that canopy cover can be directly mapped without the need to interpret mixed pixels by linear models (e.g. Herrmann et al., 2013; Larsson, 1993). This is an important factor, as the Sahelian vegetation largely depends on rainfall (Hickler et al., 2005) causing huge inter-annual variations in mixed pixels and making conventional change detection methods unreliable. This problem was often solved by trend

* Corresponding author at: Ährenweg 7, 95448 Bayreuth, Germany. Tel.: +49 176 47303955.
E-mail addresses: martin_brandt@gmx.net, matin.brandt@gmail.com (M. Brandt).

http://dx.doi.org/10.1016/j.jag.2014.08.007
0303-2434/

analysis of time series (e.g. Brandt et al., 2014b; Anyamba and Tucker, 2005). However, these datasets begin in the 1980s and do not provide any information on the situation prior to the severe Sahel droughts. Beside aerial photography, Corona imagery from the 1960s is a source that offers unique pre-drought information on the Sahel. Moreover, it documents a time of beginning human expansion and clearance of natural bushland. So far, many studies use a qualitative approach, applying case studies and/or visual inspection to reconstruct the pre-drought Sahel with aerial photos and Corona imagery (e.g. Herrmann et al., 2013; Brandt et al., 2014a; Tappan et al., 2004; Gonzalez, 2001). Land- and tree-cover changes have also been mapped (e.g. San Emeterio and Mering, 2012; Ruelland et al., 2010; Tappan and McGahuey, 2007; Elmqvist, 2004; Tappan et al., 2000) using a variety of methods (see Ruelland et al., 2011). The studies revealed that most of the former bushland has been transformed to agricultural land and a significant reduction of tree density has been observed with a spreading of barren land and considerable impoverishment of woody species (Brandt et al., 2014a; Herrmann and Tappan, 2013; Gonzalez et al., 2012; Ruelland et al., 2010; Tappan et al., 2004; Elmqvist, 2004). These changes have significant effects on the ecosystem and people's daily lives. The dependence of the local population on the products from trees such as fire and construction wood, medicine and religious purposes (Maydell, 1990) is a factor of practical importance adding significance to regional-scaled environmental studies.

In greening and desertification debates, generalizations are commonly used, attempting to simplify a reality which is far more complex. We dismiss these paradigms and show the complexity and spatial variations on a local scale. High resolution panchromatic Corona imagery of 1967 and multispectral RapidEye imagery of 2011 form the basis of this study, which includes parts of the Dogon Plateau and the Séno Plain in the Sahelian zone of Mali. The two major aims are:

1. To investigate and quantify land cover changes over 44 years including aspects of degradation and human expansion.
2. To analyze changes in woody cover between 1967 and 2011 and find explanations for these.

Materials and methods

Study area

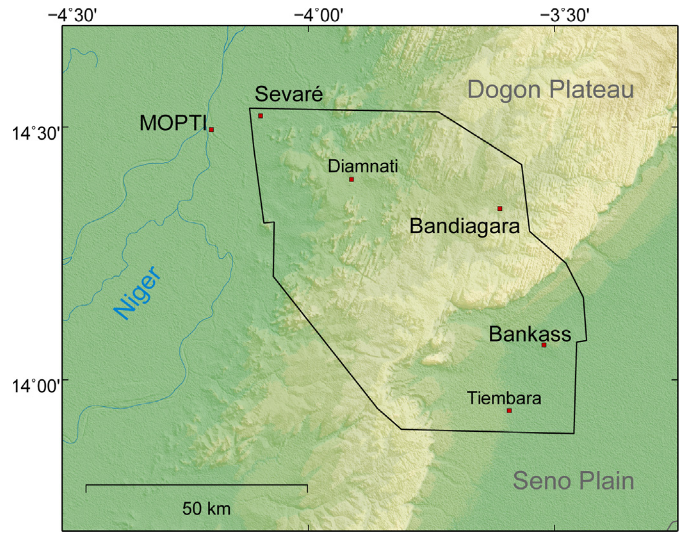

Fig. 1. The study area is located on the Malian Dogon Plateau and on the Seno Plain.

The study area is located in the Mopti Region in Mali. It is approximately 3600 km^2 large, featuring the towns of Sevaré in the north-west, and Bandiagara and Bankass in the east (see Fig. 1). Generally, the study area can be divided in the Dogon Plateau (75%) and the Seno Plain (25%) with the steep Bandiagara escarpment dividing the rocky plateau in the north from the sandy plains to the south. The plateau is inhabited by Dogon farmers and is characterized by a complex and rough morphology with shallow and lateritic soils. Cropping and grazing areas are spread between the rocky outcrops in the valleys. The sandstones often restrict the expansion of cropland areas so that many such spaces are dominated by dense natural vegetation, with *Combretum micranthum, Combretum glutinosum* and *Guiera senegalensis* prevailing, and in turn provide wood as an energy source. The main crops are millet, peanuts and sorghum. Onion plantations and gardens are found in close proximity to major streams, where the recent construction of small dams has enabled irrigation systems to be expanded.

The Seno Plain lies 200 m lower than the plateau at an altitude of 200–300 m with a plain morphology and sandy soils. The population density has increased during the past decades, which has had a significant impact on the land cover. Almost all areas of the Seno Plain are used for agricultural purposes today. Soils are deep sandy-loam which increase resilience to dry periods compared to the shallow soils on the plateau.

The villages on both the plateau and the plains have many large trees within the village borders and on fields in proximity to the village. These trees (mainly *Adansonia digitata*, *Balanites aegyptiaca*, *Borassus aethiopum*, *Faidherbia albida*) are carefully protected by villagers as they provide shade, soil nutrients, fruit, and wood (Brandt et al., 2014a). Farmers cut branches of trees within their own field, mostly by sustainable pollarding methods. More remote cropland is often laid fallow and trees on these fields often remain unprotected, as it is harder to patrol bush fields. Most species are officially protected and permits have to be bought from the forestry service to cut trees. However, the situation is very unclear and different interpretations of the forestry law exist. Within our study area, cutting and felling with and without permits was observed and reported by the local population. In both cases, the existence and degree of protection varies primarily according to species.

Various projects situated within the study area show the positive impact humans can have on woody vegetation. The areas around Bankass and Endé have particularly benefited from input by organizations like SahelEco and the inter-village association Barahogon (Brandt et al., 2014a; Allen, 2009; Yossi and Diakite, 2008) and many protected sites with dense tree growth exemplify the capabilities of trees to survive years with little rainfall and flourish in the long-term.

The Mopti region is covered in part by the North Sudanian zone (550–750 mm of average annual rainfall) and also by the Southern Sahel zone (350–550 mm average annual rainfall) (Yossi and Diakite, 2008). In general, the study area receives an average of 500–600 mm of annual precipitation, which falls entirely during the months of June–October with a high inter- and intra-annual variability. The 1970s and 1980s have seen several severe droughts and an overall drop of annual rainfall. Since the 1990s, annual values are increasing again, almost reaching pre-drought values in 2010 (Brandt et al., 2014a).

Data

Corona

Corona images belong to the very first U.S. earth observation satellites and provide a unique window into the past. The Corona KH-4B (mission 1102) took photographic images of the