Journal of Arid Environments 153 (2018) 66–75

Contents lists available at ScienceDirect

Journal of Arid Environments

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

MODIS NDVI trends and fractional land cover change for improved assessments of vegetation degradation in Burkina Faso, West Africa

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ARTICLE INFO

Keywords:
NDVI trends
Fractional LULCC
Land degradation
Savannah landscapes
Burkina Faso

ABSTRACT

Reduction of natural vegetation cover in the savannah of West Africa constitutes a pressing environmental concern that may lead to soil degradation. With the aim to assess the degradation of natural vegetation in the savannah of Burkina Faso, this study combined NDVI trends and fractional Land Use/Cover Change (LULCC). Fractional LULCC maps, derived from the aggregation of a 30 m Landsat LULCC map (1999–2011) to 250 m resolution of MODIS, were used to assess natural vegetation conversions in the small-scale spatial patterns of savannah landscapes. Mann-Kendall's monotonic trend test was applied to 250 m MODIS NDVI time series (2000–2011) to assess modifications of natural vegetation cover. Finally, the Spearman's correlation was employed to determine the relationship of natural vegetation degradation with environmental factors. The study revealed a vast conversion of natural vegetation into agriculture (15.9%) and non-vegetated area (1.8%) between 1999 and 2011. Significant decreasing NDVI trends ($p < .05$) indicated negative modifications of natural vegetation (2000–2011 period) occurring along the protected areas borders and in fragmented landscapes characterized by disruption of continuity in natural vegetation. Spearman's correlation showed that accessibility, climatic and topographic conditions favored natural vegetation degradation. The results can enable the development of efficient land degradation policies.

1. Introduction

Natural vegetation cover is a key component of the terrestrial ecosystem (Peng et al., 2015). The degradation of natural vegetation cover, seen as reduction in biomass or declining in the natural vegetative ground cover, constitutes a pressing environmental concern that threats biodiversity and may lead to soil degradation (Yengoh et al., 2015). Assessing the degradation of natural vegetation is therefore essential for regions like West Africa where natural vegetation is confronted with high anthropogenic pressure and extreme climate variations (IPCC, 2007). Besides, in this part of the world, reliable results on vegetation dynamics are crucial for the development of efficient forests safeguarding policies.

Studies have been assessing natural vegetation degradation based on land use/cover change (LULCC) analysis (Houessou et al., 2013; Ouedraogo et al., 2010). The technique of post-classification comparison of land use/cover (LULC) was often used to determine areas of natural vegetation conversions (Xu et al., 2010; Duadze, 2004). Conversions, seen as abrupt changes (Xu et al., 2016), refer to the complete replacement of natural vegetation cover by another type of land cover (Lambin et al., 2003), for example a change from natural vegetation cover to agriculture or to a non-vegetated cover type (e.g. bare surface), and they are often caused by anthropogenic deforestation (e.g. cropland expansion, wood extraction, change in urban extent). Several other authors have focused on vegetation productivity trends to determine hotspots of degradation (Xu et al., 2016; Kaptué et al., 2015; Harris et al., 2014; Forkel et al., 2013; Peng et al., 2012a,b; Lanfredi et al., 2004). This kind of analysis, which usually deals with time series of vegetation indices like NDVI (Normalized Difference Vegetation Index), is suitable to capture modifications occurring gradually and continually (Xu et al., 2016) in vegetation cover. According to Lambin et al. (2003), modifications of vegetation indicate more subtle changes (reduction or densification of vegetation cover) that affect the character of vegetation cover without changing its overall classification, and they are often related to changes of plant coverage or species composition (Forkel et al., 2013; De Jong et al., 2011). However, very few studies,

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https://doi.org/10.1016/j.jaridenv.2018.01.005
Received 17 March 2017; Received in revised form 14 September 2017; Accepted 15 January 2018

such as Wright et al. (2012), combined LULCC and vegetation productivity trends to monitor natural vegetation degradation. Yet, this integration could enable a more complete analysis of vegetation degradation (Wright et al., 2012) and also improve the assessment of potential driving factors.

Several environmental factors have been identified as driving vegetation dynamics. Climate through its parameters, such as rainfall and temperature, plays an important role in vegetation dynamics (Peng et al., 2015; Zeng and Yang, 2009; Nezlin et al., 2005). Over West Arica, rainfall is perceived as determining largely vegetation development (Zoungrana, 2016; Knauer et al., 2014; Traore et al., 2014). Topography is also a natural factor restricting land use change (Peng et al., 2012a) and driving vegetation dynamics (Peng et al., 2012b). Furthermore, anthropogenic impacts on vegetation cover are assumed to be motivated by accessibility factors (Braimoh and Vlek, 2005) such as roads, settlements and rivers. The link between vegetation dynamics and environmental factors has been subject of investigation in literature (Peng et al., 2012b, 2015; Braimoh and Vlek, 2005). However, little was done in the savannah of Burkina Faso especially on the relationship between natural vegetation degradation and environmental factors.

Remote sensing has become indispensable for vegetation change monitoring, since it provides updated satellite data on vegetation cover. Among the numerous remote sensing sensors, MODIS (Moderate Resolution Imaging Spectroradiometer) presents relevant assets for assessing natural vegetation degradation (e.g. conversions and modifications of natural vegetation), as it provides global data (MODIS Global Land Cover products) for LULCC mapping (e.g. Usman et al., 2015; Zhan et al., 2002) as well as NDVI data (MODIS NDVI) for vegetation productivity trends analysis (e.g. Jacquina et al., 2010). Moreover, MODIS vegetation indices have improved spatial resolution (250 m × 250 m) and were found to be better correlated to in situ measured vegetation indices in West Africa as compared to NOAA/AVHRR NDVI (Fensholt and Sandholt, 2005) or SPOT VGT (Fensholt et al., 2006). Nonetheless, dealing only with MODIS-derived LULCC and NDVI data in the fragmented savannah landscapes could be misleading due to the small-scale spatial patterns. Fragmented landscapes describe areas where continuous mosaics of native vegetation are transformed into disjunct pieces of native vegetation surrounded by a matrix of cement, grass, crops, and degraded lands (Marzluff and Ewing, 2001; Meyer and Turner, 1992). In those areas, the coarse pixels of MODIS in reality often cover a mixture of small patches of different LULCC types (Latifovic and Olthof, 2004). In this context, fractional LULCC approach in combination with MODIS NDVI-based vegetation productivity trends will be more suitable and will better represent the heterogeneity of the savannah landscapes (Gessner et al., 2013).

This idea was adopted in the present study which aimed at combining MODIS NDVI trends and fractional LULCC data to assess the degradation of natural vegetation cover in the savannah of Burkina Faso. Specifically, the study aimed to i) assess natural vegetation cover conversions in the study area between 1999 and 2011, ii) assess modifications occurred in natural vegetation cover based on vegetation productivity trends in the period 2000–2011, and iii) determine the relationship of natural vegetation degradation with environmental factors. For that, Landsat LULCC map (30 m × 30 m resolution) was aggregated to the 250 m MODIS resolution with fractional covers of the LULCC classes derived. MODIS NDVI monotonic trends were used as proxy for vegetation productivity dynamics and to assess modifications occurred in natural vegetation cover. Finally, the Spearman's correlation was employed to determine the relationship of natural vegetation degradation with environmental factors. In Burkina Faso, as in the entire savannah of West Africa where LULC is changing rapidly (Orekan, 2007), localizing vegetation degradation hotspots is relevant and crucial for policy makers who aim at food security, biodiversity conservation, and reduction of carbon emission, e.g., from deforestation.

2. Materials and methods

2.1. Study area

A study area covering 5120 km^2 was located in the Black Volta basin in the southwest of Burkina Faso (Fig. 1). This region belongs to the Sudan climate zone. As in the entire West Africa, its climate is governed by the oscillations of the Inter-Tropical Convergence Zone (ITCZ) from south to north and vice versa. According to Nicholson (2013), the ITCZ over West Africa is marked by the convergence of the north-easterly Harmattan winds that originate in the Sahara and the southwest monsoon flow that emanates from the Atlantic. The climate of the study area is thus characterized by a rainy season that extends from May to October and a dry season that occurs from November to April. Rainfall in this region shows high inter-annual variability. The mean annual rainfall amounts to 862.87 mm (1981–2012), and the average monthly temperature ranges from 26 °C to 32 °C (Zoungrana et al., 2015a).

The soils of the study area are dominated by Lixisols (Zoungrana, 2016) that have low organic matter content (Callo-Concha et al., 2012) and are very susceptible to erosion and compaction (Callo-Concha et al., 2013). Savannah vegetation of the Sudan phytogeographic zone covers the study area and is mainly composed of woody savannah. Agriculture, which is the principal livelihood activity in this area, is rudimentary with low inputs (e.g. fertilizers). Cotton and cereals (e.g. millet, sorghum, maize and rice) are the main growing crops in the southwest of Burkina Faso.

2.2. Data collection

2.2.1. Bi-temporal LULC maps

Landsat based-LULC maps of 30 m × 30 m spatial resolution covering the study area were collected from Zoungrana et al. (2015b) for the years 1999 and 2011 with woodland, mixed vegetation, water, agricultural area and bare surface as mapped LULC types. The map of 1999 (2011), with an overall accuracy of 94% (95%), was developed based on random forest algorithm classification of a combination of Landsat imagery and ancillary data (e.g. soil type and topographic data). The five LULC classes have been regrouped into three main LULC classes (Fig. 2): natural vegetation (woodland and mixed vegetation), agriculture (agricultural area) and non-vegetated area (bare surface and water).

2.2.2. Reference data for change map validation

High resolution imageries (RapidEye and Google Earth images of 2011, and Quickbird image of 2012) and aerial photos of 1999 were collected in addition to the corresponding Landsat images of the LULC maps of 1999 and 2011. All those satellite images were already geometrically adjusted and projected to UTM WGS 84 zone 30 like the LULC maps, and they enabled accuracy assessment of the generated LULCC map between 1999 and 2011.

2.2.3. MODIS NDVI data

NDVI data were collected from 250 m MODIS Terra MOD13Q1 16-day vegetation index product (2000–2011) and used as proxy for vegetation productivity. The NDVI data have been downloaded from the USGS′ MRTWeb interface (https://mrtweb.cr.usgs.gov/) and re-projected to UTM WGS 84 zone 30 by using MRT (Modis Reprojection Tool) and further resized to the outline of the study area. The Time-Series Generator (TiSeG) (Colditz et al., 2008) was used to assess NDVI data quality, correct invalid data and fill data gaps by linear interpolation. The setting UI5-CS (Perfect-Intermediate, no Cloud and no Shadow) was applied because of the closeness of its results with the undisturbed situation (normal monthly NDVI curve of the vegetative covers). The NDVI data of the year 2000 were available from mid-February to December. Therefore, to be consistent and include the year 2000 in the trend assessment, time series of annual NDVI average (from