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Monitoring ecosystem dynamics in northwestern Ethiopia using NDVI and climate variables to assess long term trends in dryland vegetation variability

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ABSTRACT

Dryland ecosystems are highly vulnerable to environmental changes. Monitoring is vital in order to evaluate their response to fluctuating rainfall and temperature patterns for long-term ecosystem safeguarding. Monitoring of long term changes of normalized difference vegetation index (NDVI) and climate variables are fundamental for better understanding of change trajectories in dryland ecosystem, and to ascertain their potential interaction with anthropogenic drivers. In this study, we identify determinant factors of dryland changes by using MODIS NDVI, precipitation and temperature data for Breaks for Additive Seasonal and Trend (BFAST) and Mann Kendall test statistic. BFAST predicts iteratively time and number of changes within a time series data to depict the size and direction of changes. Analysis of NDVI, precipitation and temperature time series data showed substantial changes during the study period of 2000–2014. There is a reduction trend in vegetation showed by the decline in NDVI, with significant breakpoints till 2009 and recovery afterwards, without a significant change in annual trends of precipitation ($\alpha < 0.05$) for the same study period. Furthermore 2 positive climate trends were founded: a) a significant positive trend on long term annual rainfall during the main rainy seasons and; 2) a significant ($\alpha < 0.05$) annual increment of the long term mean minimum and mean maximum temperature of 0.03 °C/year and 0.04 °C/year, respectively. This assessment showed that climate variables cannot be considered as the main factors in explaining the observed patterns of vegetation dynamics. Seasonal and interannual precipitation changes have a lower weight as driving factors for the reduction in vegetation trends. Hence, the decline in vegetation productivity of the region can be attributed to the increasing pressure of human activities.

1. Introduction

The increasing in human population and the subsequent demand for resource utilization, is unbalancing the resource usage and maintenance of the ecosystem's health (Bretschger & Smulders, 2012). Spatial temporal monitoring methods based on GIS and remote sensing technologies can be of great help to assess the scope and intensity of human impacts on landscapes (Inostroza, Zasada, & König, 2016), specially in regions experiencing significant amounts of transformations like arid ecosystems (Zewdie & Csaplovics, 2014, 2015). Among these ecosystems, drylands are exposed to changes linked to both climate and human modification of the landscape. The overutilization of dryland resources, has been intensifying land degradation in conjunction with climate change which can pave the way for desertification (Sivakumar, 2007). Desertification is a type of land degradation process in which a relatively dryland region becomes increasingly arid, typically losing its bodies of water as well as vegetation and wildlife (Geist & Lambin, 2004). The understanding of land degradation process and its causative factors is vital for developing sustainable land use strategies.

Monitoring of long term ecosystem changes, incorporating trend component and seasonal component is crucial for better understanding of change in ecosystem's trajectories. The availability of large spatial and temporal satellite datasets enable for monitoring of changes in land degradation, in ecosystems and

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climate changes (DeFries, Field, Fung, Collatz, & Bounoua, 1999; Roy et al., 2014). The systematic analysis and monitoring of ecosystems change is decisive for determining the driving factors and identifying the ecosystem' evolution over time (Rocchini, 2010; Vogelmann, Xian, Homer, & Tolk, 2012). Satellite imagery facilitates enormously the monitoring of spatio-temporal trends because they represent a consistent and systematic measurement, at suitable spatial scales, to capture the processes of changes over time (Roy et al., 2014; Verbesselt et al., 2010). Satellite remote sensing has played a key role for monitoring ecosystem change at the regional, continental, and global scales (Coppin, Jonckheere, Nackaerts, Muys, & Lambin, 2004) and their derived vegetation indices (VIs) demonstrated their central role in monitoring light dependent physiological processes (Cracknell, 2001; Fensholt, Rasmussen, Nielsen, & Mbow, 2009; Glenn, Huete, Nagler, & Nelson, 2008; Tucker & Yager, 2011).

The assessment of the status and monitoring of trends of drylands is vital in order to evaluate their performance with respect to fluctuating rainfall and temperature patterns, for developing long-term ecosystem conservation schemes. The variations in trends of long-term vegetation dynamics are influenced by changes in seasonal climate and other disturbance factors that can be depicted by abrupt changes in vegetation dynamics (Verbesselt, Hyndman, Zeileis, & Culvenor, 2010). The change in vegetation cover affects the amount of light absorbed by the plant canopy due to changes in vegetation density. Consequently, an analysis of the normalized difference vegetation index (NDVI) time series could be one of the major indicators for evaluating ecosystem dynamics resulted from vegetation transitions and climate change (Petropoulos, Griffiths, & Kalivas, 2014).

Ecosystem change can be categorized into three classes (Verbesselt et al., 2010): namely (1) seasonal change, which results from annual interaction of climate variables which can affect annual cycle of plant phenology (2) gradual change that includes interannual climate variability, transitions in land management; land degradation or gradual transition of land use types. In dryland areas the process of land degradation disturbs the biological cycle of the ecosystem which can result in desertification; (3) abrupt change could completely modify the system that results from disturbances among which includes deforestation, urbanization, floods and fire.

Several change detection methods have been developed to evaluate remotely sensed datasets for assessing changes in environment (Lu, Mausel, Brondizio, & Moran, 2004; Yuan, Sawaya, Loeffelholz, & Bauer, 2005). However, few methods are able to detect both seasonal patterns and long term changes without identifying abrupt changes (Jacquin, Sheeren, & Lacombe, 2010; Verbesselt, Hyndman, Newnham, et al., 2010). The identification of changes requires proper methods that evaluate seasonal variations and long term trends to properly account for systematic ecosystem' changes (Verbesselt, Hyndman, Newnham, et al., 2010). The application of efficient change analysis methods prevents the masking of seasonal variability and also allows identifying abrupt changes, helping in designing proper measures on sensitive ecosystem regions of drylands.

There is a loss of dry forests, both spatially and in a temporal scale, in semi-arid regions due to several factors, such as subsistence and large scale agricultural expansion, fire, population growth and the accompanying rising need of land and energy (Lemenih, Kassa, Kassie, Abebaw, & Teka, 2014; Zewdie & Csaplovics, 2015). Studies on change detection assessment using either socio-ecological survey or bi-temporal change detection approaches may lack a comprehensive assessment of long term trends, occurrence and timing of environmental changes. In addition, changes in the ecosystem could be both gradual and abrupt according to the involved factors, which should be identified in order to provide information on when and where changes has occurred (Verbesselt et al., 2010).

The BFAST algorithm was developed to integrate the decomposition of time series data into trend, seasonal and noise components (Verbesselt et al., 2010). BFAST algorithm identifies the number, time, magnitude and direction of changes within the trend component in order to specifically detect changes within the landscape (Verbesselt et al., 2010). The analysis investigates changes in vegetation responses along the temporal gradient and spatial domain so as to separate the possible causes and timing of changes. This study tests the BFAST algorithm for patterns in trends and the timing of abrupt changes in MODIS NDVI, precipitation time series and temperature time series data. The aim of this study is to determine drivers of environmental changes in the semi-arid region of northwestern Ethiopia, an ecosystem under severe disturbances. This analysis can help to categorize types of changes that resulted from either human impacts or changes in climate variables to design better options for sustainable environmental management.

2. Data and methods

2.1. Study area

The study area is Kaftahumera, a region located in northwestern Ethiopia with a geographic location of 13° 40′ N and 14° 28′ N latitude and 36° 27′E and 37° 32′ E longitude. The region covers an area of about 6200 km^2 holding a population density of circa 18 persons/km^2 (Central Statistic Agency(CSA) (2014); Fig. 1). The altitude ranges between 537 m and 1865 m above sea level. The region is within the semiarid Agro-ecology bordering the Sahelian region. The maximum temperature ranges between 33 °C and 42 °C. The mean annual rainfall ranges between 450 mm and 1100 mm and an uni-modal distribution with June to September becoming the main rainy season. Agriculture is the major economic activity with crop-livestock mixed farming as the prevailing mode of livelihood with sesame, sorghum and cotton comprising the major cultivated crop types.

The woody vegetation of northwestern Ethiopia is characterized by the association of *Combretum-Terminalia* and *Acacia-Commiphora* woodlands with dominant tree species including *Boswellia papyrifera*, *Anogeissus leiocarpa*, *Stereospermum Kunthianum*, *Terminalia, and Combretum* (Eshete, Sterck, & Bongers, 2011; WBISPP, 2005). The regional woody vegetation is under severe threats, due to continuous fire, over harvesting of wood, resettlement, subsistence and large scale agricultural expansions (Lemenih et al., 2014; Zewdie & Csaplovics, 2015). The lowlands of northwestern Ethiopia are among the resettlements areas for farmers from overpopulated and degraded highlands of the country since 1980s and affecting the woodland ecosystem dynamics of the region (Rahmato & van den Bergh, 1991; Rahmato, 2003).

2.2. NDVI data

MODIS (MOD13Q1 V005) Terra time series NDVI produced at 250 m spatial resolution and 16-day compositing periods was used. NDVI is widely used for monitoring vegetation photosynthetic capacity and the spatio-temporal dynamics of green vegetation (Tucker & Yager, 2011). It corresponds to a nonlinear combination of Near-Infrared (NIR) and Red band (NDVI = (NIR−R)/(NIR + R)) (Tucker, 1979). The MODIS NDVI dataset is a complement of the National Oceanic and Atmospheric Administration (NOAA's) Advanced Very High Resolution Radiometer (AVHRR) products and provides continuity for time series historical applications of