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Anthropogenic pressure in East Africa—Monitoring 20 years of land cover changes by means of medium resolution satellite data

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ABSTRACT

The East Africa IGAD (Intergovernmental Authority on Development in Eastern Africa) region with its great variety of ecological regions experienced major changes during the last decades. This study assesses and quantifies the land cover dynamics in the region by applying a systematic sampling of medium resolution Landsat and DMC Deimos imagery. 445 samples covering about 3% of the study area taken as a box of 20 km × 20 km around each 1 degree latitude and longitude intersects are processed and analyzed. Statistical estimates of land cover change are produced by means of an automatic object-based classification in seven broad classes for the years 1990–2000 and 2000–2010. Figures of change for the East Africa IGAD region are presented and land cover change processes such as loss of natural vegetation and increase of agriculture areas are analyzed. Results highlight the geographical distribution of land cover dynamics and show a 28% increase in agriculture area over the analyzed 20-year time frame. The yearly agriculture area increase rate is around 1.4% for both assessed decades, however a strong increase in yearly deforestation rate – from 0.2% in the first period to 0.4% in the second period – has been observed. These figures are discussed within the context of the drivers of changes and the resulting impact to the natural ecosystem.

1. Introduction

East Africa is often described as the cradle of humanity. For thousands of years people have been living in the area interacting and transforming the natural environment. Pastoralism, shifting cultivation, permanent or semi-permanent agriculture and agro-forestry have altered the environment to a point that the present landscape is the product of both natural variation in vegetation as well as human-induced changes (Bongers and Tennigkeit, 2010). Over the last decades anthropogenic impact and the competition over land has become an issue of major concern and even conflict among the rural and pastoral population in Africa. This is particularly true for the East Africa IGAD region where in addition to extensive agriculture expansion driven by a strong increasing population, recurring cycles of drought and famine are threatening agriculture production and hence lives of both people and livestock (Meier et al., 2007; Molvaer, 1991). Hence, since the mid 1990s the Intergovernmental Authority on Development in Eastern Africa (IGAD) aims to assist and complement the efforts of the member states in the fields of food security and environmental protection, promotion and maintenance of peace and security and humanitarian affairs, and economic cooperation and integration.

Since the early 1970s Earth Observing satellites are monitoring our planet's land surfaces at different time and spatial resolutions. From the beginning the African continent has been of major interest for this technology supporting the repeated assessment of large and often inaccessible areas. Most studies applied either low-resolution satellite data with high repeat cycles for continental assessments of changes in vegetation status and phenology providing limited information on quantitative land cover change figures (Bégué et al., 2011; Stroppiana et al., 2009; Diouf and Lambin, 2001; Lambin and Ehrlich, 1997) or higher resolution images with greater spatial accuracy but low repeat cycle applied mainly for national or local case studies (Cabral et al., 2011; Tappan et al., 2004; Pellikka et al., 2009; Jansen et al., 2008; Serneels and Lambin, 2001). An exception over the African continent is

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represented by the humid tropics and in particular the Congo Basin area which has been monitored accurately from low to high spatial and temporal resolution with both sample based methods as well as spatially continuous mapping approaches (Achard et al., 2002; Potapov et al., 2012; Mayaux et al., 2013). The reason for this being the greater interest of humid tropical forests in the global climate processes and the climate change discussion and negotiations under the United Nations Framework Convention on Climate Change (UNFCCC). A recent study of Bodart et al. (2013) provides for the first time regional estimates of forest cover and its changes in the dry African ecoregions between 1990 and 2000, using a systematic sample of medium-resolution Landsat type of satellite imagery which was processed consistently across the continent. However also this study is mainly focusing on forests and deforestation rates. In addition, its geographical coverage is limited by the dry forest areas within the Sudanian, Guinea-Congolia/Sudanian, Guinea-Congolia/Zambezian and Zambezian ecoregions (White, 1983). These are covering only marginally the IGAD region, including the southern part of Sudan and only minor areas in Ethiopia and Uganda. Finally, Brink and Eva (2011) demonstrate the capability (but also limitations) of using a regular grid of Landsat imagery samples to highlight areas of increase in agriculture and reduction of wood- and shrublands in the Somalia-Masai ecoregion (White, 1983) within the Greater Horn of Africa. Although different in the methodology – Brink and Eva (2011) is based on visual image interpretation and a higher sampling rate within the regular sampling grid – and slightly dissimilar in the study area – the Somalia-Masai ecoregion is covering only partially the IGAD region – the study of Brink and Eva (2011) shows comparable results for the 1990–2000 period over the matching areas of our study.

Biome-scale assessments are important in order to characterize dynamics and the impacts of these variations on similar vegetation types – such as humid or dry forests – in distinct ecological zones. On the other hand, regional observations and evaluations, in particular economic regions such as IGAD, are necessary to support the economic region's mission. Coordinated and harmonized policies at the regional scale in the fields of food security, habitat protection and natural resource management require also standardized and consistent monitoring and assessment of the environment at regional level.

The objective of this study is to provide land cover statistics for the year 2000 based on a systematic sampling of high accurate Landsat and DMC Deimos images over the entire IGAD region and to assess changes in a consistent manner over the time periods of 1990–2000 and 2000–2010 with a particular focus of the anthropogenic impact – defined here as agriculture expansion – on natural vegetation. The methodology is based upon the global TREES-3 project implemented by the Joint Research Centre of the European Commission to monitor tropical forest cover changes for the periods 1990–2000–2010 based on multi-date Landsat sample sites distributed systematically over the global tropics (Achard et al., 2009). The research of our study was conducted in the framework of the Seasonal and Annual Change Monitoring (SATChMo) Core Mapping Service within the EU-FP7 funded Geoland-2 project. The aim and novelty of this particular work was to further develop the TREES-3 approach- in order to assess land cover dynamics also in the agricultural domain.

2. Materials and methods

2.1. Study area

Our study focuses on the countries within the Greater Horn of Africa comprised in the IGAD region (Fig. 1), including the countries of Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda (our study was done prior the official separation of Sudan into South Sudan and Sudan, therefore in the text we refer only to the former borders of Sudan).

The IGAD region covers a wide range of climatic and ecological regions, resulting in a wide variety of land cover types and land cover change dynamics. The geomorphology varies between coastal areas to flat and gentle sloping land to high mountain areas such as Mount Kenya, Africa's second highest peak. The ecoregions map of White (1983) provides a broad overview of the key vegetation zones and their relation to climate and rainfall in the region. The natural land cover distribution is roughly mirrored in the climatic patters and the different vegetation zones of the region. The IGAD region is characterized by nine ecoregions, although two of them – the Guineo-Congolian and the Giunea-Congolia/Sudanian – are of minor relevance due to its limited area in the IGAD region. The Somalia-Masai ecoregion is the most predominant one. It covers about 33% of the entire IGAD region and is characterized by arid to semi-arid type of climate. The vegetation structure is predominantly open to closed deciduous shrubs and woody vegetation including tree and shrub savanna, which become semi-evergreen and evergreen bushland and thicket on the lower slopes of the mountain areas. The next ecoregion in importance of percentage area is the Sudanian ecoregion which covers 23% of the total area. Most of the Sudanian region lies below 1000 m and is distinguished by semi-arid climate in the North to equatorial savanna type of climate in the southern part. The natural and semi-natural vegetation is characterized by woodland and in rare cases by dry forest. But in most areas the natural vegetation has been modified by human activities. The practice of shifting cultivation, where woodland is in various stages of regrowth following a period of cultivation, is typical for this region (White, 1983). The Sahara and Sahel ecoregions which describe the northern part of the IGAD region exhibit both about 14% coverage respectively. The climate is arid and desert type, with unreliable rainfall mostly below 500 mm per year, making any vegetation grow a challenge. Wooded grassland in the South and semi-desert grassland in the North are predominant with some wood- and shrubland restricted to rocky outcrops (White, 1983). About 10% of the IGAD region is distinguished by the unique Afromontane ecoregion. This zone is an archipelago-like centre of endemism (White, 1983) which is common in tropical Africa on elevations above 2000 m. A considerable part of Ethiopia is home to this ecoregion extending North into Eritrea and even Sudan. Furthermore, the highlands and mountain areas of Kenya are represented by the Afromontane ecoregion and also to some extend the most southern and western end of Uganda. In general mean annual rainfall is above 1000 mm in the forest zone, diminishing with increasing altitude outside the forest belt (White, 1983). Below the forest belt a natural transition zone towards the bordering ecoregions is present. The remaining ecoregions have only a limited presence in the IGAD region. They include the Lake Victoria ecoregion with locally high and well distributed rainfall which is sufficient to support rain forest, but in the majority semi-evergreen forest and wood- and shrubland represent the climax. Then the Zanzibar-Inhambane ecoregion which is located along the Kenyan coast and stretches to some extend into southern Somalia. Here the typical climax vegetation is represented by forest and along the coastline Mangrove forests. However, these has been extensively cleared to make place for tree plantations and aquaculture. Finally, the Guinea-Congolia/Sudania ecoregion is characterized by an equatorial savanna type of climate comparable to the southern end of the Sudanian ecoregion.

2.2. Method

A spatially continuous – often referred to as wall-to-wall mapping – land cover change assessment may be the ultimate solution