THIRTY YEARS OF LAND COVER AND FRACTION COVER CHANGES OVER THE SUDANO-SAHEL USING LANDSAT TIME SERIES

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ABSTRACT

Despite the relevance of historical land cover maps for scientists and policy makers, an accurate high resolution record is currently lacking over the Sudano-Sahel. In this study, 30m resolution historically consistent land cover and cover fraction maps are provided over the Sudano-Sahel for the period 1986–2015. These land cover/cover fraction maps are achieved based on the Landsat archive preprocessed on Google Earth Engine and a random forest classification/regression model, while historical consistency is achieved using the hidden Markov model. Using these historical maps, a multitude of variability in the dynamic Sudano-Sahel region over the past 30 years is revealed. These include cropland expansion and the re-greening of the Sahel, forest degradation & the detection of fine-scale changes, such as smallholder or subsistence farming. The historical land cover / cover fraction maps are made available via an open-access platform.

Index Terms— Landsat, Sudano-Sahel, land cover, random forest

1. INTRODUCTION

The Sudano-Sahel is of particular interest regarding land cover and vegetation dynamics as high climatic variability is present in the region, which impacts both livelihoods and ecosystems. The Sudano-Sahel was considered to be under the imminent threat of desertification in the future. Nevertheless, many studies indicated that since this period, the region experienced significant re-greening, showing its resilient character [1].

Besides the influence of climatology, anthropogenic activities also strongly affect land cover and vegetation. Population increases led for example to higher demands for wood, agricultural lands, and livestock grazing areas [2]. Furthermore, a large portion of these anthropogenic-induced changes occur at a local scale (e.g., typical fine-scale farming) [3]. It is clear that both natural influences and human(-induced) activities are responsible for a large amount of land cover and vegetation changes over the Sudano-Sahel.

Currently, robust land cover (change) maps at high spatial resolution focusing on the Sudano-Sahel region are lacking. The goal of this study is to present a new set of consistent long-term land cover and cover fractions products at 30 m resolution for the period 1986-2015. These are the first dynamically consistent high resolution land cover maps that retrace the history of Sudano-Sahelian land cover over the past 30 years, obtained using traditional land cover mapping techniques.

2. METHODOLOGY

The workflow that is applied in this paper is a regional Landsat-adapted version of the CGLS-LC100 land cover classification workflow as described in [4].

In this study, we use Collection 1 Tier 1 surface reflectance data of Landsat 4, 5, 7, and 8 for the period 1984-2015 provided by the United States Geological Survey and available on the Google Earth Engine (GEE) [5]. This Landsat archive was processed to a Level-1 precision, terrain- and atmospherically-corrected product, while cloudy and cloud shadow pixels were flagged by the internal C Function of Mask (CFMASK) algorithm. Several pre-processing steps were executed on the data after which vegetation indices, descriptive metrics (such as median, p10,…), textural metrics & harmonic metrics (based on the a Fourier transformation) were calculated.

A random forest supervised machine learning method was used to train a land cover classification / regression model based on the metrics calculated on GEE [4]. In order to correctly predict land cover, accurate training data should be available. Ground-validated data were achieved for the year 2015 from the GEO-Wiki dataset by the International Institute for Applied Systems Analysis (IIASA) [4]. They comprise of nine land cover classes:

- open & closed forest
- shrubland
- grassland/herbaceous vegetation
- herbaceous wetland
- bare/sparse vegetation
- cropland
- urban
- water
A total of 37,824 ground-validated points over the Sudano-Sahel for which both a discrete class and percentual cover fractions were available. 67% of these points were used to train the random-forest algorithm, while the remainder was used for validation.

Historical land cover maps are generated independently from each other. In order to improve historical temporal consistency of each pixel and reduce the number of inconsistent and spurious changes, the hidden Markov model was applied on the full time series of land cover maps [6].

3. RESULTS

3.1. Thirty meter land cover products for 2015

A discrete land cover map at a 30 m resolution for 2015 over the Sudano-Sahel was generated (Figure 1). The characteristic north-south gradient of the Sudano-Sahel is well captured, with bare areas in the northern parts transiting towards grassland and shrubland, and finally, forest in the most southern sections. Furthermore, the broad agricultural areas in the north of Nigeria and surrounding the Nile river are clearly visible. The close ups shows the level of detail that is achieved with these maps (Figure 1).

Per-pixel cover fractions varying between 0 and 100% for each class are provided (Figure 2). These maps provide a large added value as they allow for much more detailed analyses of land cover and allow for easy detection of the density of the different vegetation classes.

A statistical analysis of the accuracy of the discrete land cover map is provided. An area-weighed (proportional to the total mapped area) overall accuracy of 68% and Cohen's Kappa value of 59% are achieved. Highest confusion is caused by the high similarities in the spectral signature of forest and shrubland on the one hand and shrubland and grassland on the other hand. It is noted that when accommodating for spectral similarities between neighboring classes (forest and shrubland on the one hand and shrubland and grassland on the other hand), the overall accuracy of the map increases to 83%, while Cohen's Kappa value attains a value of 78%.

Figure 1: Land cover classification at 30m for 2015, including several high resolution insets.

Figure 2: Cover fraction layers for the base land cover classes for 2015. Higher saturation indicates higher cover.
3.2. Historical land cover

Historical results for the period 1986-2015 are provided for a large part of the Sahel. In this section, we will show some examples covering different parts of the region. Figure 3 shows the evolution of land cover over an area comprising the north of Nigeria & the southern part of Niger. An increase in the area used for cropland is clearly visible in the areas close to the boundary of both countries. Based on a statistical analysis, we see that this expansion mainly occurred during the period 2010-2015 (Figure 4).

This increase in land used for agriculture is mainly at cost of grassland areas, and to a lesser extent shrubland and open forest. Apart from extensions in cropland areas, our products appear to also capture agriculture intensification. In the surroundings of the cities in the north of Nigeria for example, in 2000, patches of grassland and shrubland were still visible, whereas in 2015, these were converted to cropland (Figure 3). Apart from cropland growth, other anthropogenic influences can be identified. A decrease in areas of open forests in the southern part of the domain, can be identified (Figure 3). Despite this, also a very small increase in closed forest is noted (Figure 4). This indicates the presence of protected national parks.

Small-scale changes are often hard to detect in current historical land cover products. Our 30m resolution maps offer a nice solution. One form of land cover change at the fine-scale level is cropland expansion in the form of crop circles near the Nile river in Sudan. An example is provided for a small location southeast of the city of Khartoum (Figure 5). These irrigation circles have been constructed since 2005 and are expanding over time, with a broad expansion during the period 2010-2015. This example shows the capability of our land cover maps to discriminate not only broad-scale land cover changes, but also very detailed and fine-scale variability, which is a large added value to the community studying the Sudano-Sahel region.
4. DISCUSSION & CONCLUSIONS

A Sudano-Sahel-wide land cover map achieving an overall accuracy of 83% is produced for 2015, with noted confusion between forest vs shrubland and shrubland vs grassland. Furthermore, historical land cover products are produced for a large set of areas covering the Sahel. In line with population increases over the last decades, a clear increase in cropland areas is detected over the full Sahel, including a re-greening of the most northern parts. Apart from broad-scale changes, our high resolution 30m maps allow detecting fine-scale changes in land cover, such as the implementation of crop circles near the Nile River. The cover fraction maps that are provided facilitate the detection of subtle changes that are often missed by a discrete land cover classification.

The historical land cover and cover fraction maps provided in this study are made available via an open-access channel (https://doi.org/10.5281/zenodo.4013392) & [7], providing Sahelian experts, scientists, and policy makers with a new robust dataset that can be used to retrace and understand better the long history of vegetation and land cover changes in the Sahel.

5. ACKNOWLEDGMENTS

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