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Vegetation monitoring in refugee-hosting areas in South Sudan

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ABSTRACT

Mass population displacements put additional stress on the ecosystems and often lead to conflicts with the host communities, especially in the case of large refugee or Internally Displaced Person (IDP) camps. Therefore, there is need for the assessment of environmental impacts and, based on this, the sustainable management of natural resources between host and refugee communities. We propose a method based on high (Landsat 5,7 and 8) and very high (WorldView-2) resolution Earth Observation data to establish forest inventories combining the analysis of remote sensing satellite data along with ground-based observations in South Sudan. The resulting forest inventory mapping comprises map products on vegetation cover, tree species, and vegetation changes. We distinguished between the vegetation types grassland, shrub/tree savanna, savanna woodland, and woodland. For savanna woodland and woodland, we furthermore applied a tree species classification, differentiating between Red acacia, Desert date tree, Silak, and Doum palm. The tree species classification yielded in mean accuracies of about 61.0% for both the Landsat and WorldView based classifications, with the best results achieved for Desert palm tree and red acacia with average accuracies of 88% and 53%, respectively. The product about vegetation changes indicates a decrease of vegetation up to 50% within and in the surroundings of the refugee camps/settlement. The resulting maps can serve to estimate accessible wood resources and to identify potential harvest areas. In addition, they can support the definition of a sustainable use of wood for construction and cooking purposes for the refugee and host communities based on a community forest management.

1. Introduction

High levels of environmental degradation often stem from the dependency of highly concentrated populations upon natural resources including water, agricultural land, pastures, and forests (Foley et al., 2011; Raleigh & Urdal, 2007; Tscharntke et al., 2012). Mass population displacements put additional stress on the ecosystems especially in the case of large refugee or IDP (Internally Displaced Person) camps (Kranz, Sachs, & Lang, 2015; Spröhnle, Kranz, Schoepfer, Moeller, & Voigt, 2016). By the end of 2015, 65.3 million individuals were forcibly displaced worldwide because of persecution, conflict, generalized violence, or human rights violations (UNHCR, 2016). Weak environmental governance and the fact that displaced communities often compete for the same dwindling natural resources as the local communities exacerbates the risk of new conflicts [cf. (Lyytinen, 2009; Oshiek, 2015; Raleigh & Urdal, 2007; Thulstrup & Henry, 2015; UNEP, 2009)].

The additional needs of displaced communities for both firewood and charcoal (hereafter fuelwood) for cooking, heating and lighting purposes (Spröhnle et al., 2016) as well as their demand for shelter building material are often not addressed in a comprehensive and timely manner in the humanitarian response (Thulstrup & Henry, 2015; UNHCR, 2014). The resulting deforestation, often accelerated by commercial activities such as wood trade, charcoal making, or the fuel-intensive brick-making (Abdelsalam, 2014, pp. 89–106; Alam & Starr, 2009; Bloesch, Schneider, & Lino, 2013) may lead to long-lasting environmental impacts thereby affecting the resilience of the host communities largely depending on intact natural resources (Salih, Körnich, & Tjernström, 2013; UNEP, 2007).

A forest mapping and inventory has been recommended for the Sudanese refugee-hosting areas in the northern South Sudan by a UNHCR (*United Nations High Commissioner* for *Refugees*) environmental inception mission (Bloesch et al., 2013). Traditionally, forest mapping and inventory is carried out by fieldwork in relatively small sampling areas, which is time consuming and occasionally subjective (Foody, 2010; Haara & Leskinen, 2009; McElhinny, Gibbons, Brack, & Bauhus, 2005). In South Sudan, however, the vast areas and distances as well as difficulties of access because of the security situation make traditional forest mapping infinitely more complex (Gorsevski, Geores, &

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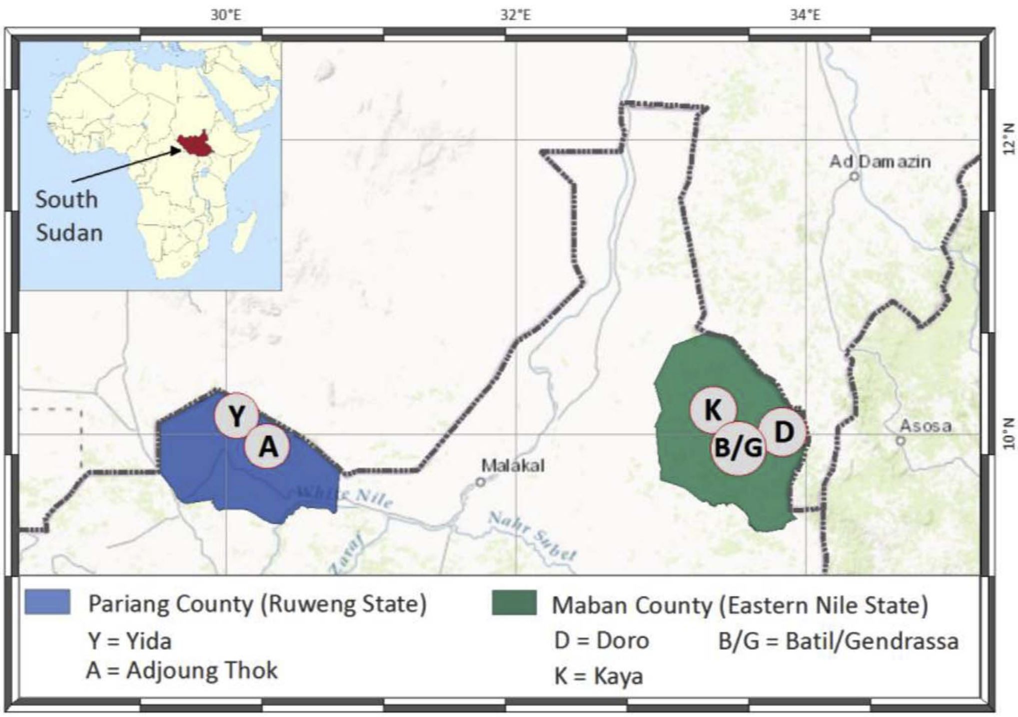

Fig. 1. Overview of the refugee camps/settlement in the counties Pariang and Maban.

Kasischke, 2013; UNESCO, 2013). Earth Observation (EO) can therefore be a good alternative to remotely map and characterize woody formations over large areas following objective criteria (Banskota et al., 2014; Mbow, Fensholt, Nielsen, & Rasmussen, 2014; Roberts, Tesfamichael, Gebreslasie, Van Aardt, & Ahmed, 2007; Tomppo et al., 2008).

For generally rather open woody formations such as occurring in northern South Sudan, high and very high resolution EO data are very suitable to map and characterize these formations [cf. (Boggs, 2010; Gara, Murwira, Ndaimani, Chivhenge, & Hatendi, 2015; Gorsevski et al., 2013; Zeidler, Wegmann, & Dech, 2012)]. EO data with high resolution (HR) are defined by spatial resolution of about tens of meters; whereas EO data with very high resolution (VHR) are defined by a spatial resolution of about 1 m (Moeller et al., 2011). There are few studies in which this kind of open woody formations and their changes have been studied supported by using high resolution EO data, including both quantitative methods and visual interpretation [e.g. (Gonzalez, Tucker, & Sy, 2012; Gorsevski, Kasischke, Dempewolf, Loboda, & Grossmann, 2012; Herrmann & Tappan, 2013; Mbow et al., 2014),]. In addition, very high resolution data were used for identification of individual trees and detailed monitoring of changes in woody cover and standing stock [e.g. (Kelder, Nielsen, & Fensholt, 2013; Rasmussen et al., 2011; Tiede et al., 2009; Wu, De Pauw, & Helldén, 2013),]. Gorsevski et al. (2012, 2013), for example, investigated the changes in land cover as well as implications for forested areas (in terms of *no change*, *loss* and *gain* of forests) during civil unrest in South Sudan. However, the authors concluded that the study was only conducted on a very minimal scale and based mainly on HR satellite data (Landsat TM and ETM+), whereby VHR data were solely used for validation purposes.

In contrast, Lang, Tiede, Hölbling, Füreder, and Zeil (2010) used multi-temporal, VHR satellite data (QuickBird) for an automatic analysis of IDP camp evolution in Darfur, but rather focused on camp's outlines and inner structure. Also, using multi-temporal QuickBird data but with stronger focus on the environmental impacts, Hagenlocher, Lang, and Tiede (2012) analysed the relationship between land cover and land cover changes and the increasing IDP camp population in Sudan. The sole use of VHR data, however, hinders an assessment of environmental impacts on larger scale. Moreover, the availability of this kind of data is limited and highly depends on the acquisition requests in the past (usually you rarely find more than 1 acquisition per year in these regions) and the data procurement itself often involves high costs (i.e. tasking new data acquisitions). Kranz et al. (2015) assessed environmental changes in Darfur induced by IDP camps on a regional scale based on free available, multi-temporal EO data of the medium resolution spectrometer MODIS. This resolution, however, would not allow an accurate estimate of wood resources for the Sudanese refugees and host communities and the identification and mapping of the dominant tree species at large scale what is a novelty of this study. In addition, another factor that is decisive for the characterization of vegetation in those areas must be considered: the temporal scale, i.e. the phenology of the vegetation (Brandt et al., 2017; Horion, Fensholt, Tagesson, & Ehammer, 2014; Symeonakis & Higginbottom, 2014). The vegetation adapts to the annual cycle of rainfall with a slight temporal delay, whereby during the long drought some parts of the vegetation withers and shows no photosynthetic activity until the next rainfall (Asner & Heidebrecht, 2002). Therefore, an important issue for the characterization of vegetation types is the use of multi-temporal data, which should be taken between the end of the rainy season and the end of the dry season [cf. (Cissé et al., 2016; Hahn-Hadjali & Schmid, 1999; Liu, Heiskanen, Aynekulu, & Pellikka, 2015)].

Thus, we propose a multi-scale and multi-temporal EO approach to derive not only the primary land cover classes and their changes but also the dominant tree species on a regional scale. The aim of this paper is i) to classify the main vegetation types for the refugee-hosting areas in northern South Sudan using multi-scale EO data, ii) to further distinguish savanna woodland and woodland based on the dominant tree species – having each a specific purpose of use [cf. (Bloesch et al., 2013)], iii) to assess changes in forest cover and thus to estimate the impact of the Sudanese refugee camps/settlement on the local ecosystems, and iv) to discuss the replication potential of the methodology for humanitarian operations. The resulting vegetation maps serve as a basis to estimate the total amount of accessible wood resources, identify potential harvest areas, and support the definition of a sustainable use of poles and fuelwood for the refugee and host communities based on a