ISSN 2316-3747

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GLP news

NEWSLETTER OF THE GLOBAL LAND PROJECT

GLP - A joint research project of IGBP & Future Earth

ISSUE Nº 12 | NOVEMBER 2015

Photo by: Fabiano M. Scarpa

Biodiversity and Land Systems

PERSPECTIVE

A new focus for ecological restoration: management of degraded forest remnants in fragmented landscapes

Land use and land cover change is the major driver of biodiversity loss in terrestrial ecosystems worldwide, making the management and governance of land systems a key parameter in conserving and sustaining biodiversity. This issue gathers 16 contributions dealing with the relations between biodiversity and land systems from very diverse thematic and regional perspectives.

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Remote sensing applications for assessing water-related risks and its interdependencies with land cover change and biodiversity in southern Africa

Abstract

Given the ongoing population growth and changes in land management as well as projected climate scenarios, a key challenge in the African sub-Saharan countries is to secure water at sufficient quality and quantity for both the stability of ecosystems, with their functions and services and for human use. Changing conditions will severely affect hydrological pattern in southern Africa, for example in terms of increasing flood frequencies and magnitudes or change in groundwater levels, which in turn will create even more pressure on existing land management pattern and biodiversity. To monitor and assess such interrelated phenomena in data scarce regions like southern Africa, innovative remote sensing data and techniques can be successfully applied. Three case studies addressing flood monitoring, wetland inundation variability and groundwater recharge in the SASSCAL (Southern African Science Service Centre for Climate Change and Adaptive Land Management) region demonstrate the potential of optical and radar satellite products to assess water-related risks and associated impacts on land cover change and biodiversity in Southern African landscapes.

Introduction

Projected climate change and socio-economic pressures like population growth and agricultural expansion are expected to considerably affect water availability and quantity, land management practices and biodiversity in water stressed regions of Southern Africa. Thus, an improved understanding of the linkages between ecosystems and society as well as their drivers is needed as a precondition to develop sustainable management strategies to cope with these changes and to improve the livelihoods of people in the region. As a joint initiative of Angola, Botswana, Namibia, South Africa, Zambia, and Germany, SASSCAL (Southern African Science Service Centre for Climate Change and Adaptive Land Management; www.sasscal.org) supports 88 research projects providing information and services allowing for a better understanding and assessment of the impact of climate and land management changes in five thematic areas: climate, water, agriculture, forestry and biodiversity.

Water related research in SASSCAL aims at providing i) reliable data, information and tools to analyse and assess present state conditions and global change impacts and ii) evidence-based services and advice for decision-makers and stakeholders supporting sustainable water resources management in the SASSCAL region (Helmschrot & Jürgens 2015). As shown by three SASSCAL case studies working on flood monitoring, wetland inundation variability and groundwater recharge, spatio-temporal remote sensing applications can notably contribute to the assessment of water-related risks and their relevance for as well as dependencies from land cover change and biodiversity in Southern African landscapes.

Case studies

Additional benefits for floodplain ecosystems observation generated from large-scale flood monitoring using high-resolution SAR (Synthetic Aperture Radar) - data in Northern Namibia

In recent years, disastrous flood events in Northern Namibia caused losses of life and disruption of agricultural and other economic activities (Tshilunga, 2014). The sudden

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occurrence and unexpected short flood recurrence intervals were associated with the impacts of climate change and variability. It is therefore expected that the frequency and magnitude of high floods will increase in years to come. Land use and land cover changes due to seasonal flooding, erosion and deposition are normal phenomena in any floodplain. However, increasing river dynamics, modifying floodplains with an undesired frequency and magnitude, can induce severe consequences on the floodplain ecosystems and cultivation, requiring a revision of regional floodplain management programs (Hazarika, 2015).

The Hydrological division of the Ministry of Agriculture, Water and Forestry (MAWF) is the responsible institution for flood monitoring and mitigation measures in Namibia. As the collection of ground data is often hampered by access to remote and inaccessible areas, Earth Observation data are used to provide area-wide information on extent and duration of major flood events. A Water Observation & Information System (WOIS), covering selected water basins in Africa, was recently implemented in order to enable the MAWF and water authorities from other African countries to generate a wide-range of satellite earth observation based information products needed for Integrated Water Resource Management (IWRM) in the continent (Guzinski *et al.*, 2014). Integrated case studies on wetland monitoring provide information on seasonal changes of wetland and permanent water bodies while selected flood mapping approaches establish suitable tools for the monitoring of changing flood conditions and unscheduled impacts on wetland ecosystems.

Within the SASSCAL project, a multi-scale flood monitoring system, combining two individual optical and radar flood mapping services, is currently under development at the German Aerospace Center (DLR) (Martinis et al., 2013) and is foreseen to be an integral part of a local flood forecasting and early warning system in the Cuvelai-Etosha basin, which straddles southern Angola and north-central Namibia. An extended flood service, using the new Sentinel-1 satellite system and covering the entire SASSCAL project area will be implemented in the near future. Major advantage of this service is the systematic acquisition strategy of the Sentinel-1 mission, allowing a utilization of SAR acquisitions for continuous monitoring purposes without the necessity of time-consuming and on demand acquisition planning. In Figure 1, an example for an observed flood event at the Shire River in Malawi using radar remote sensing is shown. Area-wide and up-to-date remote sensing data on evolving and highly dynamic flood situations feature a great potential for the assessment of flood induced land cover change in valuable wetland ecosystems. Using comprehensive WOIS information and flood service products, essential questions like the future importance of wetland agriculture for food security under climate change conditions (e.g. soil degradation, soil retention) and wetland hydrology with related impacts on water supply systems can be addressed on a large and detailed scale.

Satellite- based system for enhanced data capture capabilities for wetland biodiversity management in Western Zambia

The Barotse wetland, located in the upper Zambezi River Basin, is an annually inundated RAMSAR (RAMSAR, 2014) recognized ecosystem rich in biodiversity and supports a variety of livelihood streams for a large population in western Zambia. Continued existence of fish, livestock and other flora and fauna is principally dependent on the annual inundation regimes which occur in the rainy season between October and April of a given hydrological year. However, current and projected climate scenarios coupled with unsustainable land use practices in and around the wetland, are already showing and predicting negative impact on biodiversity.

This study was undertaken to answer to the paucity of data on the nature and potential implications of the variations in inundation regimes on biodiversity as influenced by both natural and anthropogenic activities. Time series of satellite data offer great potential characterizing historical inundation regimes, land cover changes (within and around the floodplains and wetlands) and linking these to hydrological variables and potential impacts on biodiversity. Using both optical (MODIS, Landsat) and radar (TerraSAR-X) remote sensing sensors, inundation extents in the wetland was detected (Fig. 2), quantified and characterised from 2003 to 2013. Land cover changes have been analysed between 1984 and 2015. Results indicate significant variations in inundation extent across the considered time space and show a strong correlation between inundated area and observed discharge. Significant variations in inundation will lead to negative implications on, for instance, vegetation growth (type and quantity), fish stocks and available water for crop production (after the flood recession). Observed land cover change, in particular forest cover changes, will most probably intensify the impact on wetland biodiversity due to noted downward trends in discharge and water level. Field observations during flood events also provided evidence for increased sedimentation due to land cover change, resulting in negative impacts on both the quantity and quality of water in the floodplain.

Crucial precondition for tackling future challenges of the Barotse wetlands like resource over-exploitation, flood control to protect house and technical infrastructure (Fig. 3), land drainage, encroachment for agriculture, and interference with river hydrology for large-scale hydropower and irrigation schemes, is a foresighted wetland

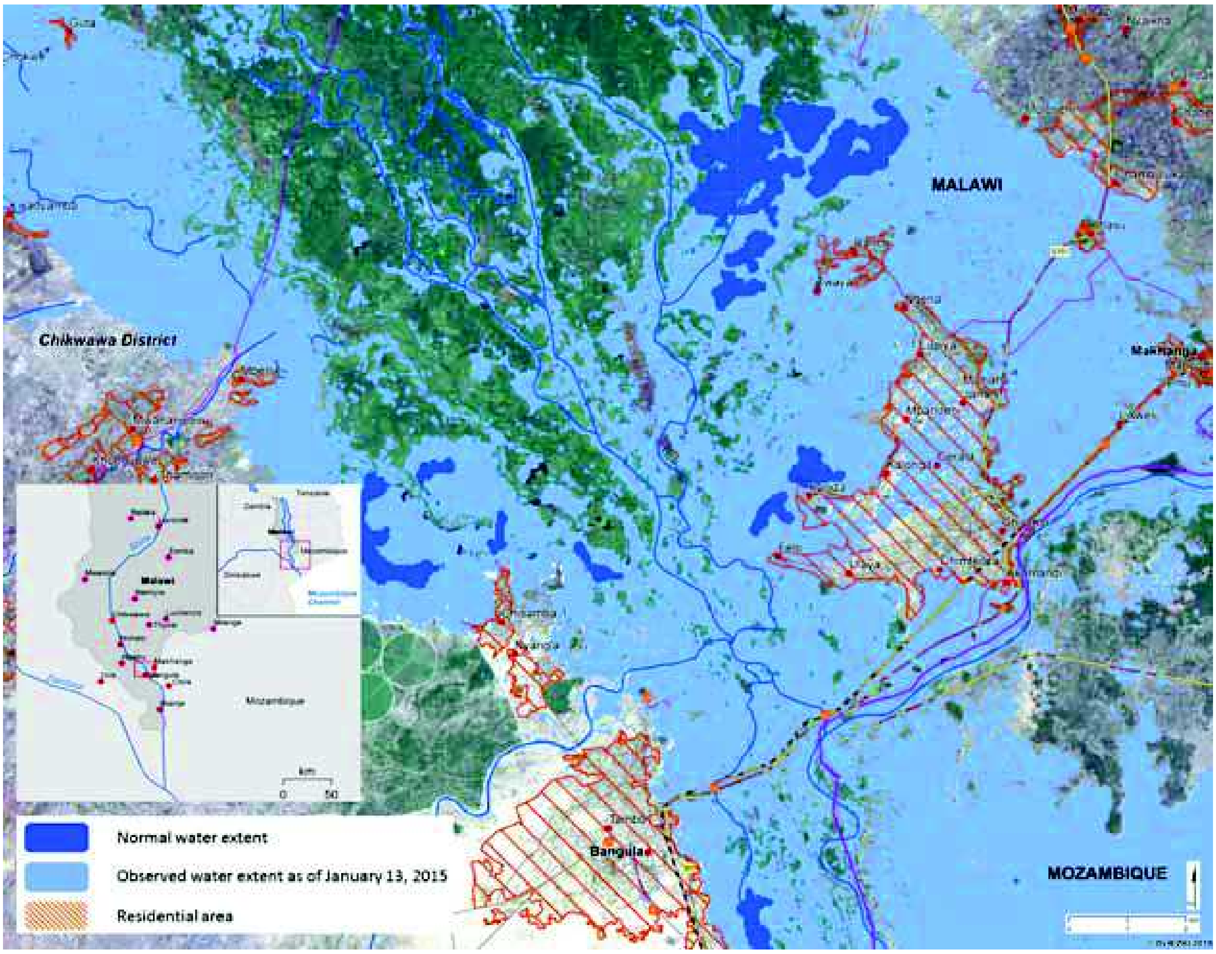

Figure 1: *Flood situation as of January 13, 2015 at the Shire River in the area of Bangula, Malawi, close to the Mozambique border. The flood extent was derived by image analysis from RADARSAT-2 satellite imagery. (Source: DLR/ZKI, 2015)*

management (Turpie *et al.*, 1999). Large-scale and detailed observation for the long-term monitoring of wetland conditions can only be managed effectively by using earth observation methods. A new generation of high resolution optical and radar satellite systems (e.g. Sentinel 1,2) with high revisit times and free data access, will provide unique opportunities in the future to improve the quality of information on inundation regimes for effective overall management of biodiversity in the wetlands.

Groundwater Recharge assessment for better understanding of local natural systems in southern Angola

Human activity plays an important role concerning the quality and quantity of groundwater. Groundwater issues not only affect the subsurface but also can have a great impact on land use if one thinks about shallow groundwater layers and vegetation or land subsidence caused by groundwater withdrawal (Phien-wej, Giao, & Nutalaya, 2006). A sustainable management depending on reliable information of groundwater recharge is crucial. The estimation of recharge rates in the Cuvelai-Etosha-Basin (Angola/Namibia), especially the Eastern Sand Zone, is the major objective of this case study. It is hypothesized that parts of the groundwater found in the south of the Eastern Sand Zone have their origin in the Angolan highlands in the north. Directly on the transition of the Angolan low- and highlands, between Yonde and Caiundo, analysis showed that water accumulates in some areas during the rainy season. Vegetation indices derived from MODIS data give evidence that near surface water is available around these zones, especially in the supposed drain direction. No patterns indicating salinization, which can be caused by high evaporation rates, were found through Landsat and MODIS data analysis. Lateral runoff seems to be marginal. Therefore, groundwater recharge is assumed to be the dominant process in these water rich areas. Due to poor accessibility, ground truthing was not possible so far. A further notable feature of this region is the direction of the drainage lines, which in most cases tend to flow south-eastwards in the highlands and bend to the south west after passing them. This abrupt change in direction can be seen as an indicator of geological boundaries or faults.

To support the theory of accumulated recharge in the mentioned areas, SAR (Synthetic Aperture Radar) Interferometry (InSAR) will be used in a further step for a pilot area. Studies have shown that InSAR can help to understand the hydrogeological behavior of a catchment (Lu & Danskin, 2001; Schmidt, 2003) by analysing land uplift and subsidence. As most of the rain in the study area falls between November to April, and nearly no rain occurs during the rest of the year, a periodic cycle of land uplift and subsidence is expected for regions with high groundwater

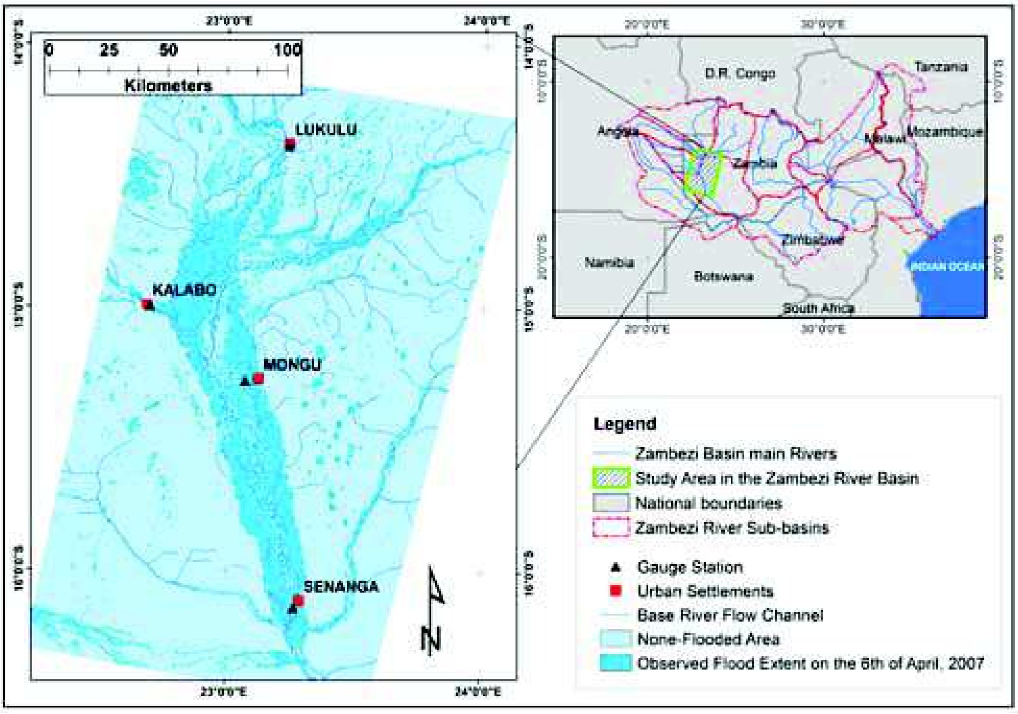

Figure 2: *Flood extent of the floodplain along the upper Zambezi River on 6th April 2007. The flood extent map was derived from Landsat 5TM using the Desert Flood Index (DFI)*

recharge rates (Bell *et al.*, 2008). If the hypothesis of intense groundwater recharge can be proven, the method could be easily extended to other parts of the basin and contribute to a better general understanding of the whole natural system. Moreover, this study will create further knowledge about groundwater-dependent ecosystems and biodiversity conservation in complex drainage systems.

Lessons learnt & outlook

- we created multi-scale time series in various reference areas in Southern Africa, quantifying and assessing water-related risks and and its interdependencies with land cover change and biodiversity using remote sensing data. These analyses provide crucial additional benefit for other thematic areas within the SASSCAL project and beyond.

-with this contribution we facilitated interdisciplinary research activities within SASSCAL and beyond, i.e. regarding cross-sectoral topics like land systems and biodiversity under climate change conditions.

- a new generation of high- resolution optical and radar remote sensing sensors provide unique opportunities for biodiversity research and sustainable economic development in Southern Africa under global change conditions. Many ground-based methodologies are difficult to use for mapping and predicting regional or global changes in the distribution of biodiversity, something that is at the core of many national and international conservation agendas (Collen *et al.*, 2013). Satellite remote sensing can make a difference in biodiversity monitoring and conservation as it offers a relatively inexpensive way of deriving complete spatial coverage of environmental information for large or remote areas. The free and open access policy to data from the Sentinel satellites will be a breakthrough in the use of satellite data for specialised users, but also for the general public. Furthermore, the status of multi-scale and multi-temporal remote sensing data as an integrative element for cross-sectoral and interdisciplinary research will increase enormously within the next years. Scientific platforms such as the group on Remote Sensing for Biodiversity within the Committee on Earth Observation Satellites (CEOS) are enabling information transfer and network opportunities and will further emphasize synergies and common research topics between biodiversity and remote sensing research (Pettorelli *et al.*, 2014).

Acknowledgements

The authors would like to thank the German Ministry for Education and Research (BMBF) for funding these SASSCAL research activties (Grant Number: 01LG1201K/M) as well as all data providers, in particular the German Aerospace Center (DLR) for providing TerraSAR-X data/ TanDEM-X Data free of charge within the framework of the TerraSAR-X Science Proposal MTH2881. We also acknowledge all participating researchers and institutions, technical assistants and local collaborators for their valuable support. The present work was partially conducted within the framework of the Panta Rhei Research Initiative of the International Association of Hydrological Sciences (IAHS).

Figure 3: *Reconstruction of the bridge on the Mongu-Kalabo Road near Mongu Harbour. The road, linking the districts of Mongu and Kalabo in western Zambia, was extensively damaged during a higher than normal flood event in 2003/2004 season. The road is envisaged to be a gateway between Zambia and Angola for enhanced economic interaction between the two countries. Though the road and bridges are being constructed there is no information on the impact the construction of this road infrastructure will have on flood extent regimes, river channels, silt deposition, or on fish and wildlife movements. This makes it more significant to have in place a flood pattern monitoring system that will facilitate for disaster management preparedness as well as biodiversity monitoring in the wetland (Photograph: Helmschrot, 2015)*

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