Proc. IAHS, 374, 123–128, 2016
proc-iahs.net/374/123/2016/
doi:10.5194/piahs-374-123-2016

Open Access PIAHS

East African wetland-catchment data base for sustainable wetland management

Constanze Leemhuis, Esther Amler, Bernd Diekkrüger, Geofrey Gabiri, and Kristian Näschen

Department of Geography, Bonn University, Bonn, 53115, Germany

Correspondence to: Constanze Leemhuis (leemhuis@uni-bonn.de)

Published: 17 October 2016

Abstract. Wetlands cover an area of approx. 18 Mio ha in the East African countries of Kenya, Rwanda, Uganda and Tanzania, with still a relative small share being used for food production. Current upland agricultural use intensification in these countries due to demographic growth, climate change and globalization effects are leading to an over-exploitation of the resource base, followed by an intensification of agricultural wetland use. We aim on translating, transferring and upscaling knowledge on experimental test-site wetland properties, small-scale hydrological processes, and water related ecosystem services under different types of management from local to national scale. This information gained at the experimental wetland/catchment scale will be embedded as reference data within an East African wetland-catchment data base including catchment physical properties and a regional wetland inventory serving as a base for policy advice and the development of sustainable wetland management strategies.

1 Introduction

As one response to emerging fundamental questions on food security in Africa, the UNEP stresses the role of wetlands for agriculture in Africa (Frenken and Mharapara, 2002) leading to an encouragement of many African governments and NGOs for wetland farming practices to improve food security, reduce poverty and facilitate the diversification of rural livelihoods (McCartney et al., 2010). Wetlands, characterized by nutrient rich soils and year-round water and/or soil moisture availability, sustain especially smallholder farmers with opportunities to produce crops all year-round (Sakané et al., 2011). Nevertheless besides provisioning services like food, water and building material, wetlands provide a range of other regulating, cultural and supporting services (Rebelo et al., 2009). An increasing agricultural use of wetlands in Sub Saharan Africa could be observed during the recent decades, mainly driven by demographic growth, climate change and globalization effects (Bond, 2014; Ulrich, 2014). Degradation of overexploited upland fields, market opportunities and the need to earn cash income (Wood and van Halsema, 2008) are key influencing factors for a shift from upland agriculture to wetland agriculture. However, such an intensification of wetland use and the resulting increase in regional food production will only be achieved sustainably if the benefits derived from diverse wetland services can be reconciled with the requirements of increased food production. Wetlands are complex ecosystems in which groundwater and surface water interact. They are commonly defined by the presence of standing water for some period during the growing season, either at the surface or within the root zone (Lehner and Döll, 2004). According to a review paper of diverse global wetland studies (Amler et al., 2015) the global wetland extent is varying between 5.6 and 12 million km^2 with a range of uncertainty depending on the used wetland definition and the pragmatic difficulty of quantifying wetlands in aerial and satellite images. The most detailed global study on wetland extent is provided by Lehner and Döll (2004) estimating a global wetland extent of 9.17 million km^2 with about 1.3 million km^2 located in Africa. Wetlands in Sub Saharan Africa consist mainly of alluvial floodplains and inland valleys and cover an area of around 0.17 million km^2 in the East African countries of Kenya, Rwanda, Uganda, and Tanzania (Stevenson and Frazier, 1999). These two dominating inland wetland types cover more than 80 % of East African total wetland area. Alluvial floodplains are described by a well-defined river in a smoothly sloped valley characterized by oxbow depression,

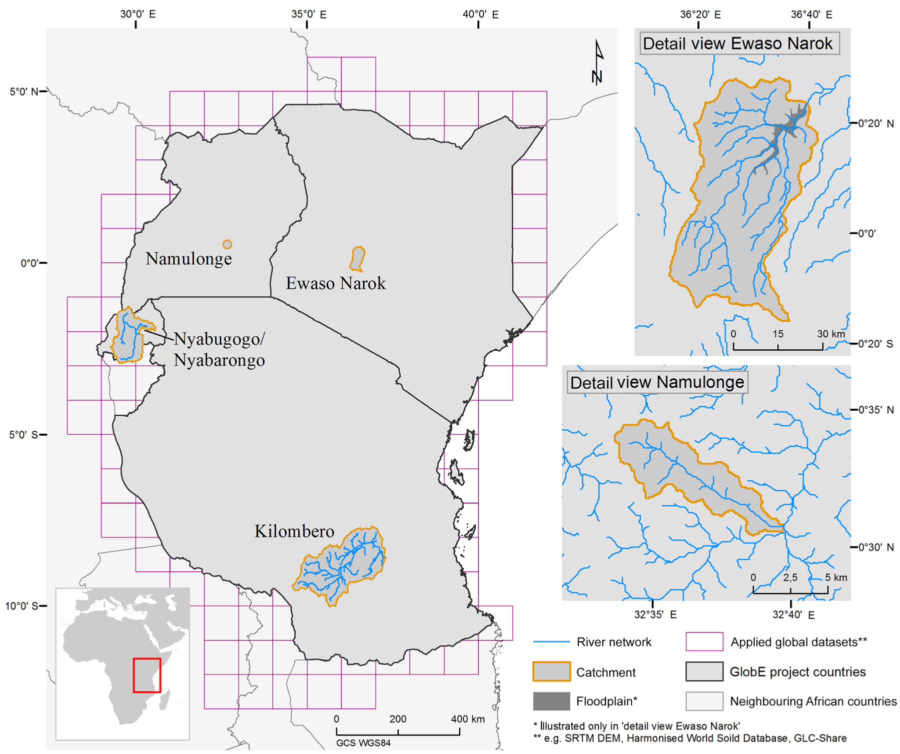

Figure 1. Nested experimental test site/regional wetland – catchment data base approach for East Africa comprising the countries Kenya, Uganda, Rwanda, and Tanzania. (http://gadm.org/, 2015 and Jet Proulsion Laboratory, 2015, modified)

natural levees and seasonal overbank flooding (Kotze et al., 2012). Inland valleys are seasonally water logged and often grass-covered linear depressions in head water zones of rivers comprising valley bottoms and hydromorphic fringes but excluding river floodplains (Mitsch and Gosselink, 2007; Rodenburg et al., 2014).

2 Methodology

2.1 Study sites

For our study (http://www.wetlands-africa.de/) we focus on the main East African freshwater geomorphic wetland types floodplain and inland valley in the countries Kenya, Rwanda, Uganda, and Tanzania. Besides the regional East African approach the scales of research are sub-divided into catchment, wetland and super test site scale (Fig. 1). Two floodplains and two inland valleys under semi-arid and humid climate conditions and their respective catchments are selected at the catchment-wetland scale (Table 1). For in-depth studies on the trade-offs and linkages of Ecosystem Services with water and matter fluxes under different land use systems, two smaller areas are selected as super test-sites for intensive in-situ monitoring campaigns. With an inland valley close to the Kampala-Jinja transect in Uganda and a smaller headwater catchment of the lowland Kilombero floodplain in Tanzania the two selected super test-sites cover our main priority wetland types of the overall research area in East Africa.

2.2 Wetland-catchment approach

The overall wetland water balance strongly determines the entire wetland ecosystem including all its functions and services (Dixon and Wood, 2003). Depending on the geomorphic setting of the wetland, besides precipitation, surface- and subsurface inflow has a strong impact on the wetland water balance. Therefore off-site factors like land use change, infrastructure measures including dams or river fragmentation and overall climate variability mainly determine the seasonal surface- and subsurface inflow and hence water availability of the wetland. In a nutshell, the off-site factors and their interactions with the physical state of the wetland determine the in- and outflow of the wetland and hence the water availability, as well as direct pressure for downstream ecosystem services. The physical state of the wetland comprises the onsite factors of physical wetland characteristics and its associated anthropogenic use. According to Kotze et al. (2012) these on-site and off-site factors influence wetland health on a scale of anthropogenic wetland degradation compared to its pristine state. Therefore wetlands cannot be described as isolated ecosystems (von der Heyden and New, 2003) and there is a strong need for a nested catchment-wetland approach to

Table 1. Wetland study sites and physical wetland and catchment characteristics, *super test-site of the project.

Catchment/study site	Ewaso Narok	Nybarongo	Kilombero (Ifakara)*	Kyoga (Namulonge)*
Geomorphic wetland type	Alluvial floodplain	Alluvial floodplain and inland valleys	Alluvial floodplain	Inland valleys
Country	Kenya	Rwanda	Tanzania	Uganda
Wetland area [km^2]	80.5	128.6	537.4	116.7
Catchment area [km^2]	2610	8900 num. headwater catchments	40 240	num. headwater catchments
Elevation [m a.s.l.]	1600–2400	1200–3000	200–2500	1100
Climate	semi-arid	humid	sub-humid	sub-humid
Annual precipitation [mm]	700	1000	1400	1350

assess its overall state of degradation within the catchment context.

2.3 Regional East African wetland-catchment data base

The core idea of a regional East African wetland-catchment data base is to capture all direct and indirect drivers forcing wetland degradation on a wetland-catchment scale. In a causal network that is based on a combination of the DPSIR analysis and the Ecosystem Services framework (van Dam et al., 2013), the strong relationship between drivers and pressures allows an assessment of the degradation state of the wetland and its associated ecosystem services (Fig. 2). First of all this requires a harmonized, area-covering East African wetland map, which is based on standardised information about wetland location, type and extent applying remote sensing technology and global geo datasets (Fig. 1).

The large East African region with remote and hardly accessible wetlands is frequently cloud-covered due to its climatic conditions. Many wetlands in East Africa underlie a strong seasonality which needs to be considered and incorporated in a wetland map. These challenges in mapping of East African wetlands can be overcome by the combination of different sensor systems with a multitemporal data analysis approach. By now the publicly available, regularly recorded time series of medium to coarse resolution satellite data e.g. MODIS (NASA MODIS Data, 2015) and SPOT (VITO, 2015) are expected to be able to capture the distinct seasonality of wetlands, especially in comparison to their surrounding uplands. A map product which is compiled based on this rationale can be enhanced by data acquired from sensors with higher spatial resolution, e.g. Sentinel 2 (European Space Agency, 2015) which started its operational phase in 2015. In addition a regional East African catchment data base is needed to characterize the direct and indirect drivers for wetland degradation including demography, infrastructure measures and physical catchment properties in space. Physical catchment properties like e.g. topography, geology, soil, land use, and climate strongly determine water availability for each specific wetland and can be spatially represented by a regional hydrological model like e.g. the spatially distributed mesoscale hydrologic model mHM (Samaniego et al., 2010). Due to limited data availability the entire regional catchment data inventory has to be based on freely available global geo- and climate datasets like e.g. the Harmonised World Soil Database (Nachtergaele et al., 2012) and GLC-Share (Latham et al., 2014) for regional land use data. These freely available geo datasets are constantly evolving through improved methods in geostatistics in combination with increasing databases which lead to more precise and higher resolution datasets (e.g. Hengl et al., 2015). In order to select an optimum global geo- and climate dataset for the application of the mesoscale hydrological model simulating water availability on the regional East African scale the most suitable datasets are applied and assessed on the experimental catchment scale with the distributed process-based hydrological catchment model SWAT (Arnold et al., 1998). This ensemble modelling further serves as a model performance measure of the regional mesoscale hydrologic model that is using an ungauged modelling approach. On the experimental wetland scale small-scale hydrological processes and water related ecosystem services under different types of management are analyzed and wetland boundary conditions under varying climate and land use/infrastructure scenarios are simulated with the distributed hydrological catchment model SWAT. The multi-scale approach allows evaluating the agreement between regional and experimental wetland-catchment approach especially with respect to the significance of off-site factors on ecosystem services.

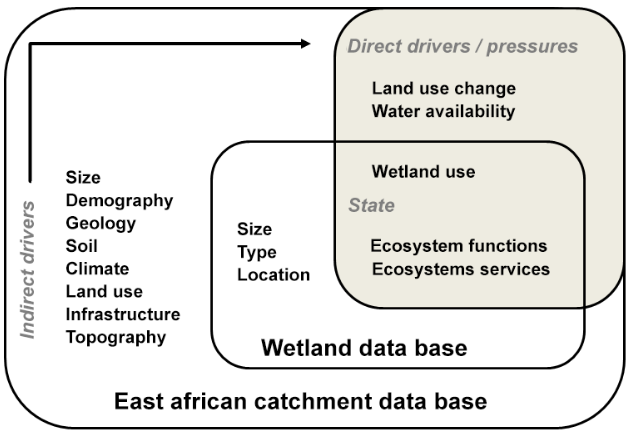

Figure 2. Conceptual model and data structure of the nested East African wetland-catchment data base.

3 Discussion

A combined DPSIR analysis/ Ecosystem Services framework can assist wetland policy and management by incorporating formal and informal knowledge about the functioning of the wetland system and analysis of trade-offs between human and ecosystem health (van Dam et al., 2013). Moreover the DPSIR approach allows a comprehensive mapping of the agriculture – wetland interactions identifying complex causal interrelations, multiple options and levels of response (Wood and van Halsema, 2008). There are a number of Sub Saharan African studies looking at wetland-agricultural interactions and their associated ecosystem services (Beuel et al., 2016; McCartney et al., 2010; Wood and van Halsema, 2008; McCartney and Houghton-Carr, 2009; Kotze et al., 2012). These studies are mainly conducted at the wetland scale and require a detailed on-site survey, always telling a unique local wetland story. However for regional environmental planning of sustainable wetland use a multiple scale analysis embedding the regional, catchment and wetland scale is needed. Rodenburg et al. (2014) have described a couple of studies that outline the regional or national potential of inland valleys with GIS analysis, spatial modelling and remote sensing techniques for identifying agricultural inland valley development potential. These studies map the inland valley agricultural potential but do not analyze the direct and indirect drivers and pressures leading to an exploitation of the wetland and hence a loss of ecosystem services and are furthermore lacking a study of hydrological wetland-catchment interactions. The experimental wetland-catchment framework serves as an overall reference data set to assess the analytic potential of the regional wetland catchment data base for sustainable regional and national wetland management. This includes in-depth hydrological process studies at the wetland scale looking at the impact of wetland management options on water related ecosystem services. Beyond the experimental wetland scale embedded catchment studies analyze the impact of indirect/- and direct drivers like e.g. climate variability and land use change on water availability, and hence the main direct drivers determining wetland water availability as a key pressure of water related ecosystem services of the wetland and down-stream users. Here water availability is one of the key direct drivers mapping regional hotspots of likely wetland degradation. For example land use change to subsistence and large scale agricultural farming leads to an overexploitation of water resources by river abstractions in one of our experimental test sites located in the Upper Ewaso Ng'iro North Basin, Central Kenya (Mutiga, 2010; Aeschbacher et al., 2005). This upstream catchment based direct driver has an immense impact on the water availability of the associated downstream wetlands like e.g. the Ewaso Narok wetland and hence on diverse water-related ecosystem functions and services. Here regional agricultural water management programs like promoting water efficient irrigation or crops and enforcing water abstraction permits for particular large scale agriculture farming by the local water authorities would help to regulate the uncontrolled water abstractions for crop irrigation and mitigate the direct impact on the water balance of the wetland. Due to the limited hydrological and meteorological data availability in East Africa, a spatially distributed mesoscale hydrological model that is based on global-data sets and embedded in a regional wetland-catchment data base is a promising tool to assess the off-site factors of wetland degradation at the regional scale. An assessment of model performance based on experimental catchment studies is needed to further evaluate the potential of the regional wetland-catchment data base for national and regional sustainable wetland management.

4 Conclusions

Wetlands perform a range of environmental functions and provide manifold socio-economic benefits to local communities and a wider population in developing countries (Dixon and Wood, 2003). For regional environmental planning a harmonized transnational comprehensive wetland-catchment data base is needed to assess wetland ecosystem services in a catchment context and identify hotspots of wetland degradation to foster further local sustainable wetland programs.

5 Data availability

Country borders in Fig. 1 were downloaded from http://gadm.org/download. The applied SRTM DEM in Fig. 1 was downloaded from USGS earth explorer (USGS, 2016) (http://earthexplorer.usgs.gov/) and modified with Arc SWAT where the authors of the article know that the SRTM DEM has errors which affect the modeling of river network and catchments. The delineation of the estimated floodplain in Fig. 1 is described in Beuel et al. (2016). The modified SRTM data as well as the approximate floodplain extent can be directly requested from the first author Constanze Leemhuis by e-mail.

Acknowledgements. This research is conducted under the GlobE: Wetlands in East Africa project, which is funded by the German Federal Ministry of Education and Research (FKZ: 031A250 A-H), with additional funding provided by the German Federal Ministry of Economic Cooperation and Development. Many thanks to our East African partners and all colleagues of the GlobE: Wetlands in East Africa project, who provided data and assistance.

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