



An integrated social-ecological assessment of ecosystem service benefits in the Kagera River Basin in Eastern Africa

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Received: 12 March 2017 / Accepted: 8 May 2018 / Published online: 10 July 2018
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Abstract

Sustaining multiple ecosystem service benefits in transboundary river basins is a complex and challenging task in the developing world. This can be attributed to conflicting conservation and human development needs and exacerbated by climate change impacts, especially episodic drought and flooding events. We use a case study from Rwanda in the Kagera River Basin in Eastern Africa to contextualize and examine how land use cover change, water access, and agro-ecosystems are vulnerable to myriad human and natural drivers of change. An integrated framework is employed for a nested social-ecological assessment of ecosystem service benefits drawing upon landscape and vulnerability mapping, agro-commodity value chains, and institutional analyses. The conceptual framework and case study provide leverage points for vertical and horizontal linkages that include cross-sectoral partnerships, multi-level governing networks, integrated water resource management, and livelihood security. Moreover, synergy between development and conservation outcomes can be achieved through joint adaptation planning and stewardship initiatives at the local district level with full participation of resource users and community leaders. These lessons from Rwanda and the Kagera River Basin provide opportunities for mainstreaming adaptation and development planning and building resilience towards regional environmental change in Eastern Africa.

Keywords Ecosystem services · Land use cover change · Climate change · Livelihoods · Vulnerability mapping · Value chains · Kagera River Basin

Introduction

The Kagera River Basin is a social-ecological hotspot in Eastern Africa bordering four countries, namely Rwanda,

Burundi, Tanzania, and Uganda. The Kagera River is the main upper headstream to Lake Victoria and the Upper Blue Nile and provides multiple ecosystem services in the region. Ecosystem services are the goods and benefits that nature

Editor: Marc J. Metzger

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s10113-018-1356-0>) contains supplementary material, which is available to authorized users.

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provides either directly or indirectly to individuals and households, communities, and national economies. These may include provisioning services such as food and raw materials, supporting services such as pollination and nutrient cycling, regulating services such as water purification, and cultural services such as recreation and social amenities (MA 2005; Brauman et al. 2007). Ecological concerns in the region include deforestation and land use cover change (LUCC), over-harvesting of natural resources, agricultural intensification, nutrient run-off, wetland degradation, and invasive species including water Hyacinth (Tolo et al. 2012; Wasige et al. 2013). LUCC in the Kagera River Basin through urbanization and the use of wetlands for intensive agriculture have ramifications for habitat loss, water quantity and quality, and carbon sequestration. Population increase, and other human development drivers, have also affected the quantity and quality of these ecosystem services. With climate variability and temperature increase (REMA 2011a; RoR 2011), these ecosystem services are highly vulnerable and could precipitate unplanned migration, food shortages, and loss of livelihood, as well as human security concerns (Reuveny 2007; Musahara and Rao 2009).

The Rwandan side of the Kagera Basin comprises of fertile agro-ecosystems and major lakes that are catchments to Lake Victoria and the River Nile. These resource systems contribute about 50% of the country's GDP through agriculture, tourism, and extractive resource sectors (RoR 2013). However, trade-offs do exist amongst ecosystem services in such riparian regions affecting various stakeholder groups and surrounding communities (Swallow et al. 2009). Trade-offs also have a negative impact on the use of other services at different time lags (Bennett et al. 2009). The real challenge lies in enhancing synergy and complementarity between diverse stakeholder activities across jurisdictional boundaries. Efforts by national governments through legislative changes tend to be insufficient due to poor enforcement and cross-scale impacts such as nutrient run-off and pollution (Wasige et al. 2013). Emerging governance mechanisms that promote synergy between food production systems and water governance initiatives do recognize integrated management approaches (FAO 2012). Governance becomes more urgent in such regions where poverty and development needs are high and climate change exacerbates vulnerabilities and well-being (Lwasa 2015).

Two questions guided the research design in this paper: (i) How do trade-offs in ecosystem services affect local livelihoods and economic development? (ii) What decision-making approaches can contribute to synergy and resolve the multi-scale impacts on development and conservation goals in local watersheds? Recognizing that natural resource management and climate change concerns are “wicked problems” (Ludwig et al. 2001), it has been suggested that human dimension and governance approaches are imperative to attain

mutual co-benefits in policy and planning (Head and Xiang 2016; Paavola and Hubacek 2013). Unlike “tame problems” that can be solved using conventional management and engineering tools, wicked problems defy definition as they are socially complex, interconnected to other public policy issues, and involve multiple stakeholders with contradictory viewpoints and incomplete knowledge (Rittel and Webber 1973; Conklin 2005; Khan 2011). This multi-scale regional study aims to assess how ecosystems services can be governed to meet multiple stakeholder expectations under changing climate using a social-ecological systems (SES) perspective. The rest of the paper is divided into five sections: starting with study region, conceptual framework and methodological approaches, results, discussion, and conclusion.

Study region

Biogeography and resource systems

The Kagera River Basin covers an area of about 60,000 km² in Eastern Africa with 16.5 million people relying on agrarian and fishing activities in four countries. The river basin consists of three upper headstreams, two from Rwanda and one from Burundi that flows towards the Rusumo Falls at the border of Rwanda and Tanzania. The Akanyaru and Nyabarongo flow from Southwestern and Northwestern Rwanda, respectively, and confluences to become the Akagera in South Eastern Rwanda. The Akagera meets with the Ruvubu from Southern Burundi and flows through several lakes and wetlands towards the border of Rwanda and Tanzania into Lake Victoria and the Blue Nile. The Eastern province of Rwanda is home to several important lakes that contribute to the basin notably the Lakes of Bugesera (including Rweru) and those within the Akagera National Park, a biodiversity treasure under climatic threat. The associated marshlands are composed of less developed peat and provide several functions such as water reservoir and flood protection through various flora such as *Cyperus papyrus*. The forest ecosystems are very diverse with both endemic and introduced species of flora and fauna that provide food, spiritual, and medicinal benefits.

The sub-region falls under three climatic zones namely humid, sub-humid, and semi-arid zones that are comprised of several ecosystem and resource types. The ecosystems are diverse including lowland forest, woodlands in the Western Guinea-Congo belt, and highlands and hills in the Eastern afro-montane region (Tolo et al. 2012). The resources range from arable land, wetlands and water resources, fisheries, forestry, and grasslands, to cultivated lands and human-built settlements. The unique agro-climatic zones in the Kagera Basin favor agriculture; hence, agrarian activities in the form of smallholder and rain fed agriculture and livestock rearing are the major livelihood opportunities.

Governance mechanisms

There is no formal regional governing institution at the Kagera Basin level, although there are project initiatives (e.g., Nile Basin Initiative) to coordinate integrated water resource management and food production (FAO 2012). In Rwanda, Vision 2020 and the Economic Development and Poverty Reduction Strategy (EDPRS) provide the governing frameworks to attain institutional partnerships amongst various stakeholders that deals with natural resources, environmental governance, and economic development (RoR 2013). However, with multiple institutional mandates and sectoral objectives on ecosystem services, it is imperative for the coordination of cross-cutting policies on resource management to be effective in its implementation at the district and regional level (REMA 2007a; UNEP 2011). Land reforms under the National Land Policy and Organic Land Law and the Crop Intensification Program (CIP) have spurred many initiatives towards ecosystem management and poverty reduction measures (RoR 2012). These new measures are under the second phase of the EDPRS II (RoR 2013). From 2005 to 2010, there was a decline in poverty head count ratio from 57 to 45 under EDPRS I (RoR 2013). Similarly, from 2006 to 2011, there was a 12% poverty reduction success according to government statistics (NISR 2012). This was made possible through several local and home-grown initiatives especially in rural areas that targeted income improvement in agrarian livelihoods, alternative livelihood strategies, social safety nets, and cash transfer programs. Key amongst these home-grown initiatives includes the *Girinka* program, allocating one cow per poor household, and providing other social welfare benefits to address extreme poverty in rural communities. Other measures include agricultural transformation through land consolidation and crop intensification, and integrated water management strategies (RoR 2010a; RoR 2010b). At the national level, there are efforts to strengthen transboundary institutional capacity towards conservation outcomes and environmental protection, as well as the sustainable management of water resources under climate change.

Ecosystem service drivers and trade-offs

Human development activities in the Kagera River Basin have affected land use change and local ecosystem functions. The region has one of the highest human population densities with communities relying on predominantly agrarian activities (Clay and Lewis 1990). From a wicked problem perspective, such environmental concerns are difficult to separate from economic and social issues, due to their coupled SES dynamics and human-natural interactions (Ludwig et al. 2001; Conklin 2005). Urban development and agricultural intensification have affected water use and contributed to nutrient loading and eutrophication (Wasige et al. 2013). Similarly,

clear cutting of trees and shrubs in wetlands for agricultural activities in watersheds have increased stream flow, which in turn has exacerbated siltation and vulnerability to flooding. Intense water use for irrigation purposes has also affected wetland habitats and their ecological function (REMA 2011a). Addressing some of these concerns through afforestation measures and the introduction of exotic tree species including Pines and Eucalyptus have created new problems such as loss of soil nutrients and water abstraction (RoR 2010a). Such failed interventions point to the dilemmas in planning and the need for holistic approaches that speak to linkages and feedback loops. This assessment aims to provide a deeper understanding of natural and human-induced drivers of global change and its policy implication on ecosystem service benefits at the regional and local levels. The local level assessment and field work focuses on the Eastern Province in Rwanda as 75% of the land area lies within the Akagera catchments (Bertilsson and Jagerskog 2006; Tolo et al. 2012).

Materials and methods

Conceptual and analytical framework

Given the wicked nature of environmental development policies (Ludwig et al. 2001), we offer an integrated framework that considers the ecological and human dimensions of ecosystem services and its benefits across scales. We focus on how human needs in *society* interact with *ecosystem services* through resource extraction and commodity flows that benefit users and enhance economic development and well-being. Well-being is linked to human development and societal outcomes and is understood to include not only materiality and good health but also kinship ties and security, as well as freedom and decision-making attributes for self-actualization (MA 2005). Multiple interacting *drivers* including population growth, increasing commodity use, and climate change negatively impact well-being and exacerbate resource degradation (Bryan 2013). This often leads to trade-offs in ecosystem services and undesirable *outcomes* that undermine both conservation and well-being (Gordon et al. 2010). By linking social and ecological processes and their *interactions* (and feedbacks), we integrate the ecosystem service and well-being literature into a holistic approach that addresses broader *governance* and policy integration issues (MA 2005; Ostrom 2009; Braat and de Groot, 2012; Reyers et al. 2013). This is crucial to strategic planning and best management practices for integrated climate action through adaptation, mitigation, and resilience as shown in Fig. 1. Both adaptation and mitigation strategies are crucial for global change impacts especially relating to climate change hazards and natural disasters as highlighted in the Paris Agreement. *Adaptation* is understood as a response to actual or expected impact by reducing harm and improving opportunities to be

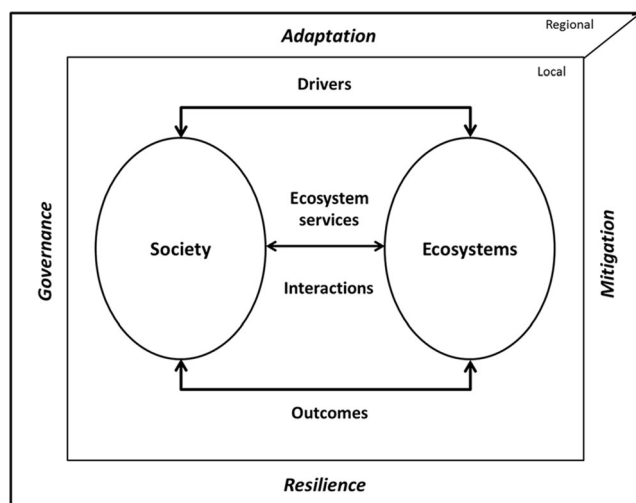


Fig. 1 Framework for assessing ecosystem service benefits under climate change (adapted from MA 2005; Bennett et al. 2009)

resilient through multiple pathways such as ecosystem-based approaches, social welfare, market-based incentives, institutional structures and policies, and technological innovation. Complementarily, *mitigation* focuses on carbon storage and sequestration, low carbon development, and afforestation programs that reduce disaster risks especially in river basins (RoR 2011).

The conceptual framework is holistic to discern ecosystem services and disservice (Zhang et al. 2007) and highlights multiple drivers in both the social and ecological systems, as well as disconnects between stakeholders who work in institutional silos (Paavola and Hubacek 2013; Reyers et al. 2013). Owing to the top-down management model of most natural resource sectors, and the conflicting objectives amongst stakeholders, vertical and horizontal linkages are crucial for cross-sectoral partnerships, stakeholder networks, and multi-level governance (Khan et al. 2016). For sustained benefits and successful outcomes, Ostrom (2009) recommended ten secondary variables that include the size of resource systems, system productivity, predictability of system dynamics, resource unit mobility, number of users, leadership, social capital, knowledge systems, resource importance, and collective choice rules. Moreover, how these variables interact to affect outcomes is fundamental to institutional design and in resolving wicked problems. Reconciling stakeholder needs and preferences provide an opportunity to design appropriate interventions to deter trade-offs and to foster knowledge brokerage towards mutual understanding (REMA 2007b).

Collective action is central to the SES thinking; hence, an understanding of users and stakeholders is important (Ostrom 1990; Paavola and Hubacek 2013). We focus on two main ecosystem service beneficiaries, notably private and public users. The distinction is relevant if the benefits of the ecosystem services are extractive (direct benefits especially for

provisioning services) or non-extractive (indirect benefit, e.g., towards cultural services), in addition to the level of binding rules and social norms. Thus, focus on the governance of ecosystem services provide users with the principles for self-organization and collective action (Ostrom 1990) and in resolving wicked problems of climate change (Grundman 2016). Governance plays a crucial part in the adaptability and resilience of ecosystem functions by promoting user participation and partnerships towards ecosystem stewardship (Folke et al. 2005; Paavola and Hubacek 2013). Positive SES outcomes reinforce synergies through policy integration of adaptation and mitigation and address trade-offs as in the case for payment for ecosystem services (PES) and ecosystem-based adaptation. Furthermore, multi-level governance arrangements are crucial for scale matching and fit between the systems to be governed and the governing institutions especially in a transboundary river basin context (Lebel et al. 2013).

Data collection and analysis

Four main approaches were employed for data collection and analysis using mixed-methods: (i) literature review and document analysis; (ii) participatory observation and focus group discussions; (iii) key informant interviews; and (iv) GIS and spatial analysis. The SES framework guided the methodology from data sources, collection and interpretation, scoping exercises, and nested analyses at multiple scales. Whereas questionnaires were useful field instruments to engage resource managers and stakeholders on the nature of ecosystem service benefits and effective governing mechanisms at the local and national level, GIS and remote sensing tools were instrumental in examining the geospatial dimension of LUCC using secondary ancillary data at the community and regional scale.

Literature review and document analysis

First, a policy review was undertaken of legislative and governing frameworks, trends in biodiversity loss and land use changes, and management measures. The review provided the opportunity to assess land use policy over time for the periods 1984 to 2014, collect pertinent information, and estimate the impact on various agro-ecosystems and livelihoods. Secondary data was collated at the national level, consisting of socioeconomic data (and related GIS shape files) obtained from the National Institute of Statistics Rwanda (NISR), specifically from the Second and Third Integrated Household Living Conditions Survey (NISR 2007, 2012). Data on hydrological profiles and watersheds were obtained from both the Department of Lands and Mapping and Rwanda Environment Management Authority (REMA), as well as shapefiles from the Centre for GIS at the National University of Rwanda. Baselines for delineating agro-climatic zones and resource

livelihoods were obtained from the USAID Famine Early Warning Systems Network data depository and the EU Freshwater Biodiversity project. These datasets were also relevant when examining resource use and livelihood activities especially in identifying and assessing value chains for agricultural commodities and the geospatial analysis.

Participatory observation and focus group discussions

Prior to the interviews, two field visits were undertaken, which entailed participatory observation and focus group discussions. The first field visit was about ethical approval and testing of research instruments, starting with an evaluation of data quality and sources, and the identification of key informants. During the second field visit, focus group discussions were held with two cooperatives, a group of women social entrepreneurs who weeded out invasive species from Lake Rweru and made household baskets for sale, and a group of male farmers who were interested in eco-certification schemes with the Rwanda Bureau of Standards (RBS). The purpose of the interviews and focus groups were to shed light on best practices for the implementation of the District Development Plans (DDPs) and to inform local consultative process in meeting Rwanda's Vision 2020 and the EPDRS II (District of Bugesera 2012; RoR 2013). Understanding how stakeholders self-organize and achieve sustainable outcomes in land use, water resource management, and agro-ecosystems is valuable for the resilience of resource-dependent communities and for regional economic development.

Key informant interviews

A questionnaire was designed and adapted to fill in gaps from the Second and Third Integrated Household Living Conditions Survey on demographics, assets, income, expenditure, and land tenure (Component 1). For Component 2, we relied on Ostrom's (2009) system variables with specific focus on resource management and environmental governance structures and processes. Our rationale for the two components was to use household data at the district level for socio-economic and livelihood assessment, to be complemented by resource management data and institutional analysis at the national and regional levels. Component 2 became the central field instrument for the key informant interviews with the availability of the national datasets, which was primarily relied on, in lieu of Component 1. The questions in Component 2 were designed to include closed, open-ended, and pair-wise comparisons to assess synergies and priorities on stakeholder preferences (see Annex 1 in Supplementary Information) and other ecosystem service and resource management considerations. Emphasis was also placed on analyzing commodity value chains and integrated livelihoods, as potential valuable opportunities for complementarities between development

and ecosystem stewardship. Two crops, maize and pineapple (one staple food crop and one export crop), were used to assess and understand revenue generation and value addition opportunities "from farm to plate." Based upon information gathered from the questionnaires on institutional mandates and partnership, collaborative governance arrangements were assessed and mapped using network analysis and visualization software Gephi (Jacomy et al. 2014). We posit that stakeholders who have more strategic relationships and communication ties with other actors could influence decision making for positive SES outcomes. The network mapping is relevant for devising strategic partnerships and institutional linkages amongst stakeholders involved in resource management and climate adaptation planning (Khan and Amelie 2015). The more connected one is with multiple stakeholders and the more "central" one's role is in influencing change and facilitating local and regional level action (Bodin and Crona 2008).

The key interviewees included 40 participants in total, of which of 21 were government officials of which 13 were from national agencies (at managerial level from ten departments) and the remaining eight from district and sector administrations. In addition to government officials, 17 non-state stakeholders were interviewed. They comprised of three industry representatives from a brewery, tourism, and agro-commodity sectors (tea and coffee industry); two community groups including farming and non-farming cooperatives; and three NGOs with one local and two international entities, four farmers, one fisher, two food processors, and two retailers. In addition, we interviewed two representatives from academia and UN agencies (see Table 1 in result section). Snow-ball sampling was used taking into consideration the diversity of stakeholder groups and the spatial scale of the regional analyses.

GIS and spatial analysis

Vulnerability hotspot mapping was undertaken at the provincial level in Eastern Rwanda to identify ecologically and biologically sensitive areas and adjacent communities exposed to these changes in ecosystem service benefits. Using ArcGIS tools, five data shape files were overlaid to assess and map community resources and livelihoods that were at risk to climate variability, as well as estimated areas of agro-ecosystems under threat. The data files in the form of GIS compatible polygons and georeferenced shapefiles comprised of (i) land use and land use change patterns including soil erosion rates; (ii) resource types and ecosystem boundaries comprising of wetlands and agro-ecosystems; (iii) socioeconomic and livelihood activities specifically farming, fishing, ecotourism, and live stocks; (iv) administrative and political boundaries; and (v) hydrological networks and flood risk zones. The integrated SES maps were compiled for two seasons, the rainy and dry, coinciding with climatic episodes of flooding and droughts,

respectively. For the dry season, emphasis was on the impact of drought on agricultural activities and livelihoods, focusing on drought risk zones and water loss. For the rainy season, soil erosion rates and land slide risk zones based on land use criteria were instrumental for assessing loss and damage. Furthermore, land use areas were computed for settlement types affected, croplands damaged, impact on lakes and wetlands, and available forest cover in seven districts in the Eastern province of Rwanda. The percentage of livelihood vulnerability for both seasons was estimated as a fraction of household income lost by district (with the four livelihood activities having equal weighting, a quarter each). The forgone

income or loss and damage per district was obtained from the Integrated Household Living Conditions Survey data and mapped for both drought and flooding episodes. The final maps were generated using spatial and non-spatial data sources analyzed through a raster-based approach produced by ArcGIS 10.1 software.

For regional LUCC analysis, Landsat images with a spatial resolution of 15 and 30 m were employed to assess land cover change over three decades from the early 1980s to 2014 for the four countries in the Kagera Basin region. Due to the size of the study area, several satellite imageries were required, corresponding to various topographical landforms, agro-

Table 1 Institutional dimension of ecosystem service governance

Institutions contacted	Type	Ecosystem services of primary interest	Focus areas and priorities
Ministry of Finance (MINECOFIN)	Government	Provisioning, regulating, supporting, and cultural	Strategic planning and economic development
National Agric. Export Board (NAEB)	Government	Provisioning	Value addition and export revenue
Rwanda Environment Management Agency (REMA)	Government	Provisioning, regulating, supporting, and cultural	Ecosystem management and environmental protection
Rwanda Natural Resources Agency (RNRA)	Government	Provisioning, regulating, and supporting	Resource management and conservation planning
Rwanda Development Board (RDB)	Government	Provisioning, regulating, supporting, and cultural	Eco-tourism and investment promotion
Rwanda Bureau of Standards (RBS)	Government	Provisioning and cultural	Quality controls, standards, and market access
Electricity Water and Sanitation Agency (EWSA)	Government	Provisioning, regulating, supporting, and cultural	Water and energy security
District Office	Government	Provisioning, regulating, supporting, and cultural	Rural planning, livelihoods, and regional economic development
Rwanda Agricultural Board (RAB)	Government	Provisioning	Food production and marketing
National Institute of Statistics Rwanda (NISR)	Government	Provisioning, regulating, supporting, and cultural	Planning and R&D
Private Sector Confederation (PSF)	Industry	Provisioning, regulating, supporting, and cultural	Revenue generation, industrial growth, and economic development
Microfinance agency	Community	Provisioning and cultural	Providing grants and regional development
Bralirwa	Industry	Provisioning, regulating, and supporting	Beverage production
Eco-lodges	Industry	Provisioning, regulating, supporting, and cultural	Tourism and hospitality industry
World Conservation Society (WCS)	NGO	Provisioning, regulating, supporting, and cultural	Biodiversity conservation
Cooperatives	Community	Provisioning, regulating, supporting, and cultural	Food and livelihood security, and region economic development
UN agencies (UNEP, FAO, and WFP)	Multilateral	Provisioning, regulating, supporting, and cultural	Institutional capacity, food security, environment, and development synergy
Caritas International Rwanda	NGO	Provisioning	International dev. and social safety nets
National University of Rwanda (NUR)	Academia	Provisioning, regulating, supporting, and cultural	Tertiary education, R&D, policy, and technical support
Nile Basin Initiative (NBI)	Multilateral	Provisioning, regulating, supporting, and cultural	Regional cooperation and integrated watershed management
NGOs (other local NGOs)	NGO	Provisioning, regulating, supporting, and cultural	Human dev, livelihoods, and environmental conservation

ecosystems, land use, and settlement patterns. The satellite images were retrieved from the EarthExplorer database of the United States Geological Survey (USGS¹). The images were procured in Level 1T preprocessing format, which means that geometric correction including orthorectification has already been applied by USGS. The object-oriented approach was used for land cover classification, as it considers group of pixels and the geometric properties of image objects. The approach partitions the images into homogeneous regions based on neighboring pixels' spectral and spatial properties and based on a supervised maximum likelihood classification, with a Kappa Coefficient of 86–87 and overall accuracy of 88–89% (see error matrix in Annex 2 of Supplementary Information). The results and analyses are presented below.

Results

We identified three key activities that lead to trade-offs in transboundary river basin contexts, with the goal of exploring governance mechanisms in meeting stewardship and development outcomes. Assessing trade-offs also offers entry points for alternative management regimes and institutional partnerships for integrated livelihood programs. We also explore two policy windows that encourage synergies and complementarities across sectors and multiple levels of governance.

Trade-offs in development and conservation priorities

Land use cover change and agricultural intensification

The quest to meet the needs of a food-secure urban population has prompted policy changes that exacerbated LUCC in the Kagera River Basin in general. The various resource systems have undergone high level of LUCC resulting to loss in ecosystem services particularly forest cover. The conversion of grassland and forests into farmlands in the Kagera Basin peaked in the 1970s and 1990s and further exacerbated by unplanned urban development (Wasige et al. 2013). As shown in Fig. 2, while the total estimated change in forest cover decreased by about 41,650 ha/year for the entire region over three decades, crop land increased significantly, with a spike in cultivated lands of around 653,807 ha over the past 30 years, at a rate of 21,794 ha/year. Likewise, urbanization has increased in the Kagera River Basin with a total land area estimated at 217,048 ha and increasing at a rate of 7235 ha/year.

These changes are more pronounced in some countries than others and vary based on resource and land use types. In Rwanda, these drivers of change are reflected in the national and district level food policy (Kathiresan 2012; RoR 2012). The priority towards food security has led to the government's

CIP initiative that targeted six major crops for both local consumption and exports. So far, the CIP has accelerated food production, which, together with land reforms, have boosted local production especially for tubers (potatoes and cassava) and rice. These developments have prompted conservation policy responses to address issues around environmental management and food production in an integrated manner. About 90% of the Rwandan population depends on agrarian activities and agro-commodity industries (NISR 2012). Interview with local resource users in the Bugesera district underscored the significance of agro-ecosystems for livelihood and food security. Cultivated croplands and livestock were identified as the most significant resources linked to household assets. This is followed by forestry and fishery resources. The governance of these key agrarian livelihood activities has implications for integrated climatic action, through adaptation planning and climate mitigation strategies, especially towards flood protection and LUCC as vegetation cover can buffer soil erosion and nutrient run-off.

Moreover, the intensification of agro-food systems has led to concerns about pollution, especially regarding the excessive use of fertilizers and pesticides. The average fertilizer use increased from 8 kg/ha in 2010 to 23 kg/ha within a few years (RoR 2010a). Although there is a guiding framework for fertilizer use based on a precautionary traffic light system (Kelly and Murekezi 2000), monitoring and surveillance measures are not robust and require capacity and human resources. Respondents identified the current research by the Rwandan Agriculture Board conducted on organic fertilizer use and its impact on yield as a necessary step towards sustainable production and an ecosystem-based approach to agriculture.

Water supply and catchment protection

Managing transboundary water resources under changing climatic conditions was identified by resource managers as one of the most daunting challenges to address, as water is linked to food production and livelihood security as well as industrial development. Despite Rwanda's abundant groundwater and surface water for domestic and industrial needs, there have been continuous challenges in access, utilization, and demand by various stakeholders. Resource users identified agriculture and food production sectors as having the highest water needs compared to the urban industrial and domestic sectors. The agriculture sector used about 150 million m³ in 2000 (Kabalisa 2006), of which rice farming constituted the highest for irrigation purposes (about 20%). Household water needs was quite low in demand, although this varied considerably depending on the type of settlement. Consumption has been estimated at 48 l/day/per home in major cities and 10 l/day/per home in rural villages. On average, Bugesera and Kayonza Districts in the Kagera Basin in Eastern Rwanda have the lowest water supply capacity of about 22 and 26 l/capita/day

¹ <http://earthexplorer.usgs.gov/> last accessed August 12th, 2017.

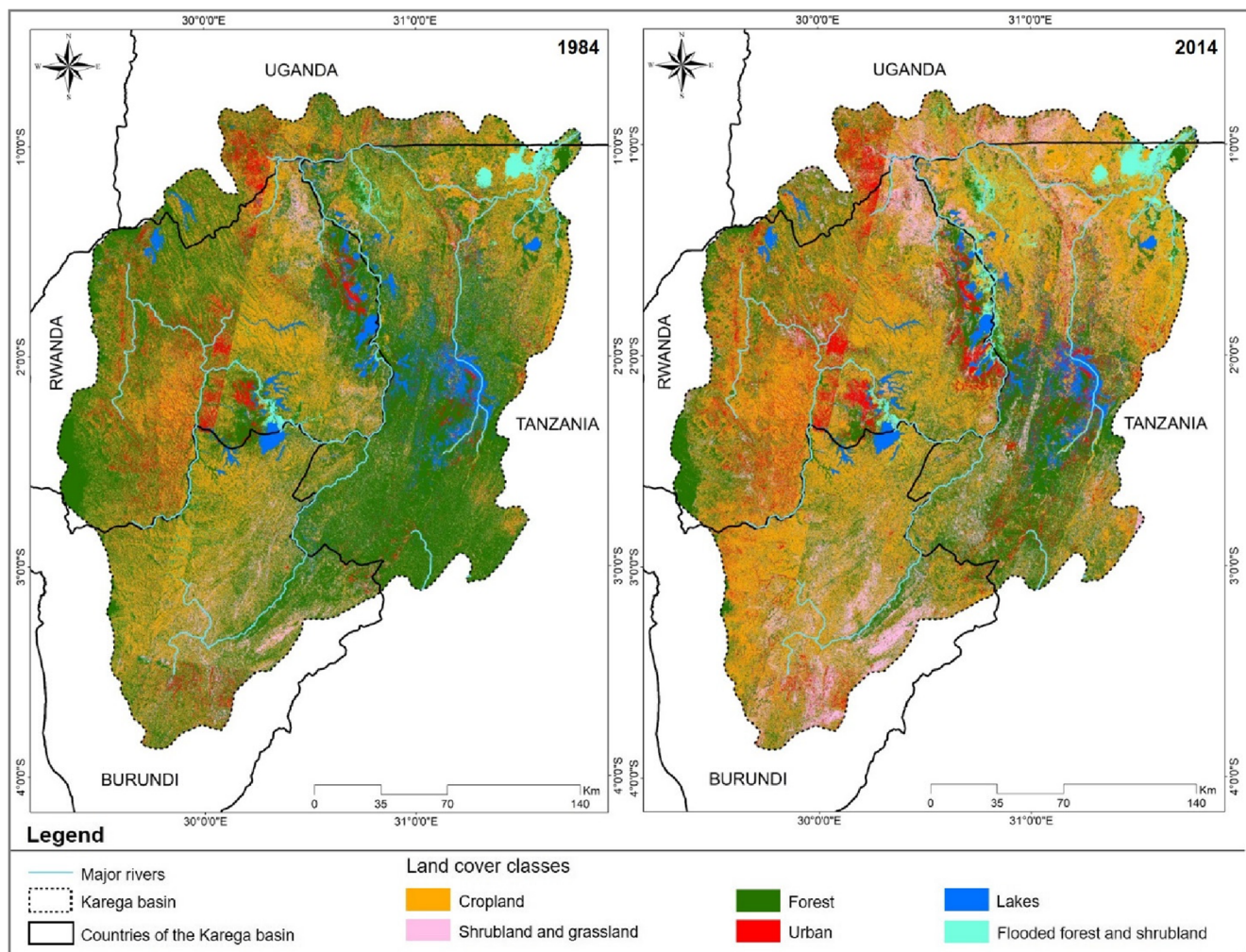


Fig. 2 Land use cover change in the Kagera Basin from 1984 to 2014

compared to urban settlements (RoR 2010a). In meeting corporate social obligations, industrial beverage companies that use water as primary inputs are now engaged in sustainability initiatives such as tree planting, youth training on environmental stewardship, and PES (Bralirwa 2011).

Additionally, new initiatives have been identified in managing watersheds under climate extremes. These initiatives mostly involve water use reforms and market-based instruments for both individual and industrial users (Kazoora 2013). Industrial stakeholders in the water utilization sector (especially coffee and tea growers and beverage companies) emphasized their involvement in cleaner production practices and joint sensitization programs on water resource management and catchment protection. District councilors are also implementing various initiatives as part of their DDP to encourage afforestation, buffer zones for tree cutting, and sustainable livelihood initiatives especially around Lake Rweru. For example, a prominent women's cooperative called COVAGA was actively engaged in weeding out invasive species (water Hyacinth) in smaller wetlands in Gashora District and using the harvested plants to produce baskets and artisanal

products for sale. Bigger and more important wetlands such as around Mugesera are however protected through buffer zones under the Organic Law N° 04//2005 and Ministerial Order N° 008/16.1.

Due to the reliance on agriculture combined with the high population density, wetlands along watersheds have been encroached on and converted into cultivable farmlands through irrigation and seasonal livestock grazing. There has been rapid conversion of wetlands to farmlands in the last decade (RoR 2010a). Moreover, many key plants in wetlands are harvested for domestic purposes such as roofing, which impedes local stewardship efforts. The effects of wetland conversions and resource extraction in watersheds have implications for flood control, water purification, nutrient recycling, and other ecosystem functions in the Kagera Basin.

Livelihoods vulnerability and food security

Ten agro-climatic zones are found in the Kagera Basin characterized by altitude, soil type, and vegetation cover. These agro-climatic zones are also highly intertwined to specific

resource systems and livelihood activities. As highlighted by one resource manager, the various agro-climatic zones are susceptible to multiple climatic hazards (such as prolonged drought and floods) and impact the viability and sustainability of agrarian livelihoods. Livelihood vulnerability is understood in the context of loss and damage to income and natural capital assets due to multiple drivers, consisting of global economic and environmental change. The level of livelihood dependence is highly connected to resource types (especially agro-ecosystems and the National Park), which are susceptible to seasonal floods in the rainy season and droughts in the dry season. These episodic events have varying impacts on resource units and users especially for agricultural activities, and water quantity and quality. Communities in resource-dependent and agrarian districts that have multiple livelihoods (e.g., farming, fishing, livestock, and eco-tourism) are highly vulnerable to floods and drought and incur more damage compared to service industries. As shown in Fig. 3a, livelihood vulnerability in Bugesera District during floods is higher due to total loss in income in three major socioeconomic activities (i.e., 75% as three quarter of livelihood activities are affected, i.e., farming, livestock, and fisheries). Compared to Kayonza District, where eco-tourism is the only dominant livelihood activity, the percentage loss is relatively smaller, just a quarter (25%).

Flooding episodes are common during the rainy months of September to January and March to June. During this time, heavy rainfall and storms produce run-offs that affect forest cover, soil nutrient, and sediment flow into catchments and lakes. According to Municipal Councilors interviewed, the risk reduction strategies and guidelines for DDP fall under the Land Use Development Master Plan. Erosion control measures and land use policies are based on soil type and slope characteristics as recommended by the Government of Rwanda (RoR 2010a). Slopes less than 5° will require minimal soil conservation techniques, while those that are between 5 and 13° require erosion control methods. For slopes that are between 13 and 25°, terracing and cropping methods are required. For slopes between 25 and 50°, cultivation is allowed only as a last option if no other economic activity is feasible. For slopes that are greater than 50°, cultivation is altogether prohibited, due to potential landslides and property damage.

In addition to flooding in the rainy season, drought is the primary climatic concern impacting livelihoods and food security in the dry season. This region also has the highest agricultural water needs, which influences farmers' motivation to cultivate in nearby swamps and surrounding lakes, thereby compromising the region's ecological functions. Although there is a zero-grazing policy currently in place for wetlands, about 30% (90, 000 ha) of the

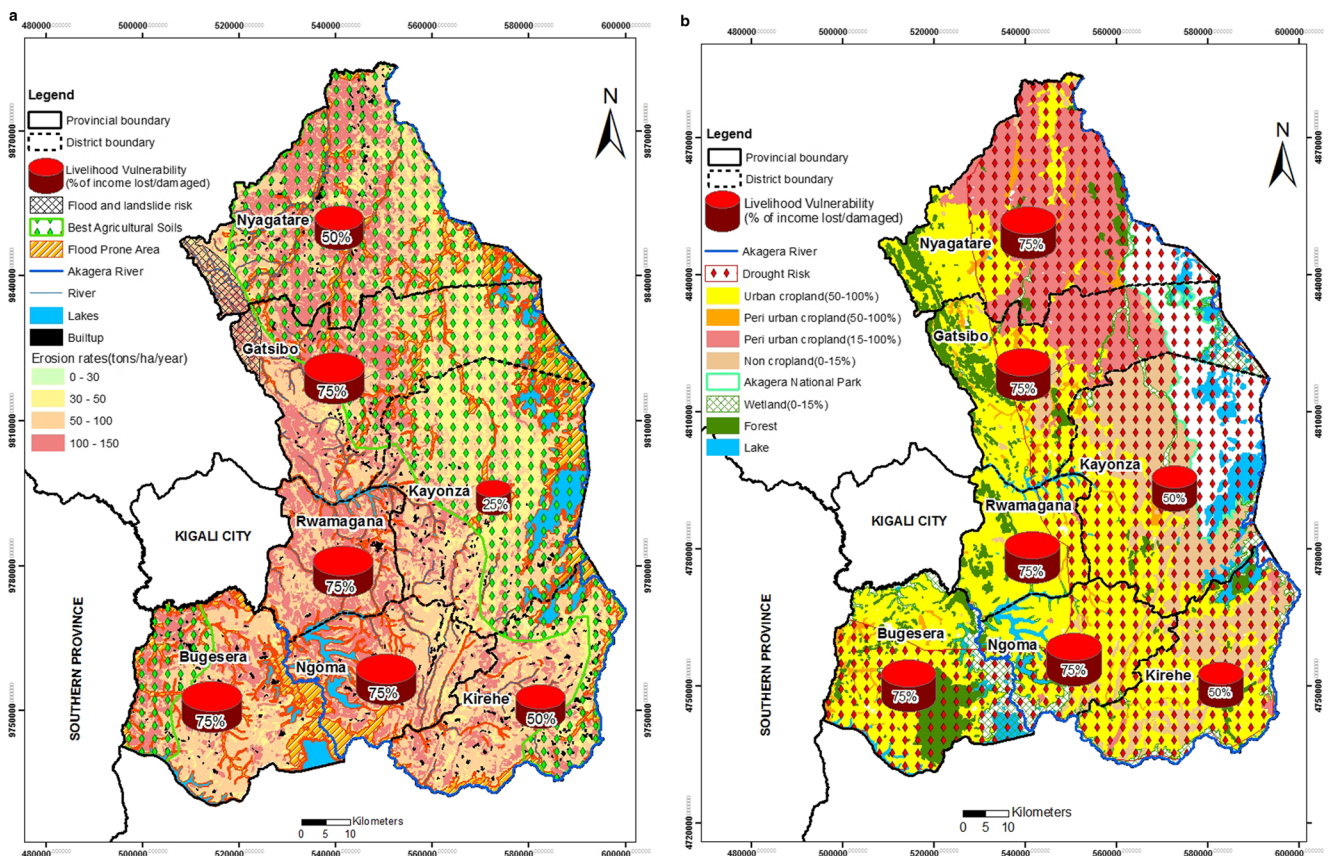


Fig. 3 a Flooding impacts in the Kagera region in Eastern Rwanda. b Drought impacts in the Kagera region in Eastern Rwanda

swamplands have already been cultivated (RoR 2010a). Resource users complained about the loss of income due to low agricultural productivity during periods of drought, causing food security and livelihood concerns. The mapping results indicate that Bugesera district is the most susceptible to drought, with the largest estimated area of urban cropland (about 75,000 ha), followed by forests ecosystems, and then wetlands. With the CIP and land use consolidation, the Eastern province has had the highest level of commercialization of agrarian activities through irrigated croplands and associated processing activities. Similarly, Nyagatare District has the largest area of peri-urban cropland affected (about 16,000 ha). Two peri-urban regions are distinguished: one with 15–50% cultivation intensity and the other with 50–100% cultivation intensity (Fig. 3b). Cultivation intensity is defined by the level of harvested crops and the yield per hectare within a given year. The two regions have different crop varieties and farming practices in terms of water needs, commodity value chains, and markets. Unlike urban irrigated croplands that focuses on staple crops, fruits, and vegetables, peri-urban croplands rely on rainfed agriculture, which have comparatively lower cultivation intensity. Unlike Bugesera and Nyagatare Districts that have relatively high cultivation intensities, Kayonza District on the other hand has the largest expanse of non-croplands, with 62% (72,000 ha) of it protected as a National Park. It also has the largest amount of water bodies and lakes (about of 17,000 ha), which makes it susceptible to encroachment by farmers and cattle grazers during drought episodes.

Stewardship and development synergies

Reconciling the multiple needs of ecosystem service benefits in watersheds undeniably requires attention to both integrated management (land and water use) and the co-benefits stemming from human development and conservation practices. These joint planning efforts are essential for ecosystem stewardship and integrated livelihoods across sectors as they support adaptive capacity and community resilience. In the next two sections, we touch on agro-commodity value chains (value chains from agricultural crops such as maize) and institutional mechanisms as part of an integrated SES thinking to catalyze social-ecological resilience.

Value chains and environmental conservation

Value chains and micro-finance were identified by resource users as crucial elements in resolving development and conservation issues as post-harvest spoilage and market failure were regional challenges that undermine their adaptability. Agro-commodity chains involve multiple stakeholders, including farmers, buyers, sellers, processors, retailers, and

consumers depending on the product type, scale of production, and target markets. From “farm to plate,” it links the environment to society through various resource sectors and production chains involving stakeholders who are governed by institutional mechanisms and market-based instruments. These governing instruments include tax breaks, subsidies, user fees, tariffs, voluntary codes of conduct such as eco-labeling, and other incentive schemes.

The chain is a metaphor to denote SES interactivity amongst stakeholder groups and potential entry points for setting conservation priorities and ecological stewardship initiatives (Annex 3 of Supplementary Information). The value chain for maize, for instance, consists of local producers who are self-organized into cooperatives and have the bargaining power to negotiate harvest price and other benefits for group membership. Price is also determined by the quality of harvest, in addition to seasonality, product form, shelf life, value addition, and market destination (e.g., local or regional export markets). Maize processing takes many forms (primary, secondary, and tertiary products) and from coarse form to fine grain or flour. The sale price of maize flour is twice that of the unprocessed form, with buyers, processors, and retailers playing a key role along the commodity value chain. We found that storage conditions and machinery account for more than 70% of the operational cost for most buyers and processors; while for farmers, labor, fertilizers, and pesticides were the key inputs that determine farm gate price. Depending on their influence and power, stakeholders can foster stewardship through extension training in soil management, water use and habitat protection measures, and marketing programs that include eco-labeling. For example, in situations where major staple commodities such as cassava are involved, farmers have organized themselves into small- and medium-scale enterprises to address livelihood security through up-scaling with the partnership of NGOs such as Caritas (Gakura 2013).

Farmers identified the need for technological innovation in local production processes, such as tractors and tillers, processing infrastructure, and storage that meets their local food security needs. For food processors, reducing post-harvest spoilage and increasing quality standards are top priorities, which require micro-finance and soft loans that are not always available at the community level. For high-end export commodities such as pineapples and water melons, which are grown year-round and target a regional niche market, the supply chain is shorter with few players but higher profit margins. For such commodities, the National Agriculture Export board sets floor prices and provides marketing opportunities for farmers and cooperatives. However, production is risky due to perishability and meeting other quality factors, such as coloration, maturity, and size. To address such market constraints, pineapple farmers have self-organized into a cooperative and started juice processing and packaging for local markets with support from a local micro-finance group.

Start-up loans and funds are often provided by micro-finance institutions that encourage small- and medium-term entrepreneurs, as there are no banking services for farmers at the village level. With increasing climate change risks for agro-commodities, micro-finance institutions are now moving towards non-farming sectors such as real estate and the transportation sector. This presents a unique policy window for farmers and banks to explore micro-insurance and revolving funds towards climate risks and community development. The usual remittances and cash transfers to deal with seasonal climatic shocks are insufficient; hence, social entrepreneurs such as MicroEnsure and the Agriculture and Climate Risk Enterprise are experimenting with insurance schemes against drought, floods, and disease for both crops and livestock (Nyasimi et al. 2016).

Policy and institutional networks

Acknowledging that environmental issues are cross-cutting and involve multiple stakeholders, REMA is mandated under the Ministry of Natural Resources to oversee and to catalyze social change with state and non-state partners owing to multiple ecosystem service benefits (Table 1). Results from the network analysis revealed the centrality of REMA in collaborating with multiple agencies and contributing to diverse goals beyond environmental protection, including regional economic planning and community development through integrated management initiatives.

In addition to the top-down management role of REMA, bottom-up structures are also prominent at the community level through self-organization of resource users into

cooperatives with the support of the Ministry of Local Government. Institutions and stakeholders that forge multiple partnerships through mutual collaboration and cooperation often show dense ties of associations through multiple social networks. For instance, the high number of cooperatives in Bugesera district with members who are engaged in both livelihood activities and stewardship programs suggest a strong linkage between the household economy and the environment. Thus, cooperatives and grassroots organizations with development and conservation partners as well as strong social ties have high levels of influence affecting successful SES outcomes as shown in Fig. 4 (Acronyms are provided in Table 1). The blue color indicates state agencies, green for multilaterals and international NGOs, orange for private sector, purple for academia, and yellow for community organizations. The size of the nodes and diameters denotes higher levels of centrality and power regarding partnerships and mutual decision-making outcomes. Paramount to governance systems is examining who works with whom in a relational matrix and the need to identify bridging organizations and institutions that can act as policy entrepreneurs for collective action. While some institutions are better placed as bridging organizations for cross-sectoral partnerships such as REMA, others are better at engaging the private sector and non-governmental actors. The Rwanda Standard Bureau is one such example; they work with the private sector and resource users on environmental and safety standards, resulting in tea harvesters achieving Rainforest Alliance certification.

Regarding conservation and development priorities, most stakeholders showed a preference for joint planning and integrated management as the most effective strategy for recon-

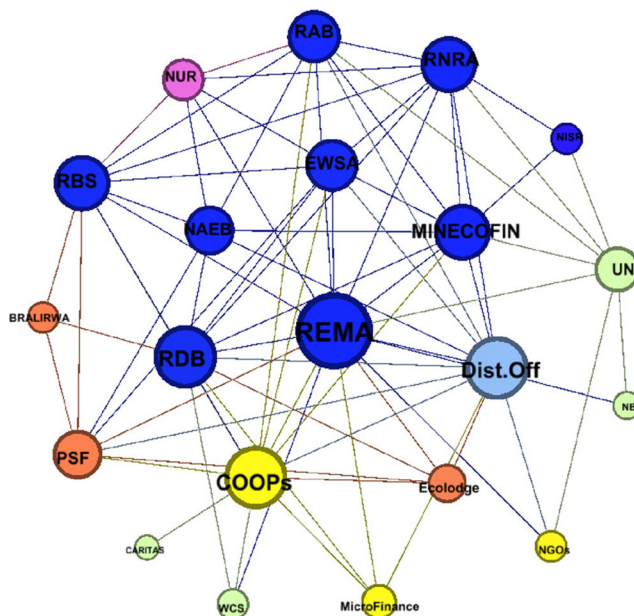


Fig. 4 Collaborating networks and institutional linkages amongst key actors

cluding wicked environmental problems. Such elicitation of stakeholder preferences help identifies common interests and areas for collaboration, particularly for critical habitats. Some respondents also identified partnership and collaboration as crucial, especially where REMA and others such as the World Conservation Society provide PES to communities around national parks. About 5% of the total revenue from user fees is allocated towards community projects through infrastructure development, training, and small community enterprises (Kagarama et al. 2011).

Resource users in the Eastern region also identified an increase in environmental stewardship within the past 5 years. Key examples cited include community tree planting initiatives, PES partnership schemes, and environmental decrees to protect lakes from farming activities and pollution.

Discussion

In unraveling the wicked environmental dilemmas facing the Kagera River Basin region, this integrated assessment identified several drivers of change and response options towards conservation and development outcomes and social and ecological resilience. Given the nature of LUCC as shown in Fig. 2, land use policy and watershed protection measures need to be integrated with food production in an ecosystem-based (adaptation) framework. Because most of the ecological problems in wetlands and catchments stem from human activities upstream, joint institutional planning and incentives for sustainable production and land use planning are central to social-ecological resilience. Rwanda has one of the highest proportions of urban and peri-urban cropland in the world (Thebo et al. 2014), which capitalizes on both irrigated and rain-fed systems to respond to emerging agro-commodity markets as well as adopting integrated management (Karamage et al. 2016). Emphasis on value chains highlights the coupled linkages between agro-ecosystems and society (for food and livelihood security) and the governance dimension to multiple conservation and development outcomes. Communities with agrarian livelihoods and linkages to multiple ecosystem services such as in Bugesera and Gatsibo Districts are the most vulnerable to both flooding and drought disasters. The percentage of livelihood vulnerability reflects the basket of resource use at stake (fraction of loss) and less so on the absolute value of damages.

The interactivity between ecosystem services and human well-being underscores the complexity of governing upstream and downstream transboundary institutions. The SES approach and multi-scale analyses demonstrate the need for collaborative governance mechanisms in creating opportunities for synergy and cross-scale linkages. For example, stewardship measures around Lake Rweru through community afforestation initiatives and PES, for instance, could have positive impacts on

downstream activities in Lake Victoria and the Upper Nile. Similarly, effective governance mechanisms at multiple coordinating levels could strengthen the adaptive capacity of local resource users and foster climate resilient development at the district level. This has been the motivation behind several international projects such as the FAO-funded Transboundary Agro-ecosystem Management Project (TAMP) in the Kagera Basin and the Initiative on Lake Victoria Environmental Management Project (LVEMP) funded by the World Bank. While TAMP aims at regional collaboration and capacity building for resource management and land use policies (FAO 2012), LVEMP focuses on the protection of large catchments to Lake Victoria such as Lake Rweru (REMA 2007b; REMA 2011b).

Within Rwanda, REMA plays an important role in its collaborative ties with district administrators, national agencies and international partners by providing a platform for cross-scale linkages in the Kagera Basin region (Fig. 4). Fully assessing the broader interactions amongst stakeholders and their organizations is the first step for policy deliberations on capacity building and governance mechanisms at regional scale (Nicols 2009). Insights from adaptive and multi-level governance arrangements have shown the usefulness of relational ties in nurturing social capital, and the role of policy entrepreneurs play in multi-sectoral planning and knowledge mobilization (Alexander et al. 2016). The various cooperatives at the local level and their multiple networks indicate a high level of collective action in strengthening the household economy as well as leveraging stewardship programs through afforestation activities.

Sustaining multiple ecosystem services, especially in the context of food and climate vulnerability, require innovative solutions such as ecosystem-based adaptation and climate smart technologies (Enfors and Gordon 2008; Khan and Amelie 2015). Integrated agro-ecological monitoring is also a commonly employed strategy for assessing thresholds and tipping points and for understanding leverage points for attaining synergy (Yevide et al. 2016). These approaches, in addition to market-based incentives and cash transfers to those affected during global change, have been crucial for successful social-ecological outcomes, as demonstrated by the Sloping Land Program in China (Fu et al. 2014). Similarly, in the Helge basin in Southern Sweden, incentive schemes and adaptation strategies were tailored to resource users who were affected by regional change (Tuvendal and Elmqvist 2011).

Conclusion

In resolving wicked environmental and climatic problems in transboundary river basins, it is important to explore conceptual and methodological tools to assess ecosystem service benefits through adaptation and mitigation strategies as well as effective governance mechanisms. We have drawn on the SES framework using mixed methods to understand

not only trade-offs but also synergies towards ecosystem service benefits and community resilience. The multi-scale case study underscores multiple drivers of change, mostly stemming from human development needs (e.g., intensive food production and urbanization) and exacerbated by climate stressors that spur seasonal flooding and drought episodes. Without adequate adaptation plans, future changes in climate will hinder many of the life support systems and will impact the attainment of the Sustainable Development Goals. Answering the two research questions about trade-offs in ecosystem services and how they affect local livelihoods and the various decision-making approaches contribute to strengthening district level adaptive capacity in contributing to DDPs, achieving EPDRS II, and exploring regional cooperation in the Upper Nile.

Such an assessment provides policy makers an opportunity to integrate conservation and development planning and establish both vertical and horizontal linkages as holistic response strategies. The findings and analyses highlight the interplay between global change drivers and local factors interacting to create vulnerabilities at different levels. To address trade-offs in ecosystem services, the various stakeholders were largely in agreement in three major areas: (a) strengthening integrated management (land use and commodity production), (b) scaling-up integrated livelihood strategies, and (c) promoting joint planning through cross-sectoral and multi-level governance mechanisms. While some adaptation and mitigation interventions might positively impact and enhance ecosystem services (through restoration of land cover and carbon sequestration), governance mechanisms could also best bridge socioeconomic and stewardship activities at various commodity production scales.

To sustain ecosystem service benefits and community resilience in the Kagera Basin, we provide three recommendations with implications for policy and practice: (i) strengthening livelihood activities through value chain development, PES, and environmental stewardship programs as part of DDP; (ii) fostering integrated management through water-energy-food nexus by the adoption of climate smart technologies to support EPDRSII and environmental monitoring at the national level; and (iii) adopting and harmonizing a common regional framework for land use planning and integrated water resources management that considers upstream and downstream linkages in the Upper Nile.

Although this study was initially designed towards a socio-economic assessment of climate risks in the eastern province of the Akagera Basin, after reconnaissance visits, it was imperative to include a biogeographical assessment and to scale-up to a regional level analysis using ancillary data. In moving forward with transboundary ecosystem service assessment, future research could be nested at multiple scales and at social-ecological boundaries using transdisciplinary tools for resilience (Metzger et al. 2008; Biemans et al. 2013). This

could include integrated scenario modeling and adaptation planning that underscores LUCC, hydrological variability, and institutional mechanisms that promote sustainable agro-commodity productions and water resource management.

Acknowledgements The first author also acknowledges *financial contribution under the Young International Scientist Fellow program* (grant no. 2012 Y1ZA0010). The research assistantship by Shaoxia Xia, Ling Ge, and Suqun Qu are greatly appreciated. Adrie Mukashema and Stephane Mugabo provided statistical data and shape files that made the livelihood vulnerability mapping possible. Thanks to Andrew Song for providing materials on preference ranking and to Jeremy Pittman for providing useful suggestions. Two anonymous reviewers provided critical comments and suggestions that strengthened the paper.

Funding information This research was jointly funded by the National Natural Sciences Foundation of China (grant nos. 31161140355 and 31361140360) and the Institute of Geographic Sciences and Natural Resource Research (CAS Grant no. 2012SJ005).

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