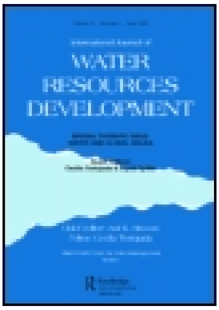

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Supporting IWRM through spatial integrated assessment in the Lake Naivasha basin, Kenya

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This study describes the mismatch between required knowledge and efforts by scientists and stakeholders in the Lake Naivasha basin, Kenya. In the basin, integrated water resources management (IWRM) suffers from the absence of critically relevant knowledge. This study further presents a spatial integrated assessment framework for supporting IWRM in the basin. This framework resulted from an ongoing debate between stakeholders and scientists studying the basin's issues. It builds on jointly identified indicators for sustainable governance, and their interdependency, and knowledge gaps. For IWRM in the basin this is a first important step towards a more structured debate on the implementation of IWRM.

Keywords: IWRM; integrated assessment; Lake Naivasha basin; Kenya

Introduction

The interdependence between human and natural subsystems of socio-ecological systems tends to become stronger when resource demand approaches the limits of availability (Molle, Wester, & Hirsch, 2010). In natural resources management, multiple perspectives and conflicting interests often lead to complex problem situations, also called 'wicked problems' (Ludwig, 2001; Rittel & Webber, 1973). Those involved in integrated water resources management (IWRM), including both stakeholders and scientists, should address such wicked problems in an interdisciplinary way (Pahl-Wostl, 2007).

IWRM is supported by advances in the development of modelling tools for evaluating the consequences of different scenarios and alternative interventions (GWP, 2001; Loucks & van Beek, 2005). Despite such progress and widespread political support, successful examples of IWRM are hard to find (Biswas, 2008; McDonnell, 2008). Similar to the more recent integrative concept of 'ecosystem services' (MEA, 2005), IWRM struggles to tighten the 'implementation gap' (Cook & Spray, 2012). Attempts to tighten this gap involve technological innovations in the fields of geographical information systems (McDonnell, 2008) and integrated assessment modelling (Jakeman & Letcher, 2003; Kelly (Letcher) et al., 2013). Such advances could promote a better factual understanding of the relevant processes taking place, and could be used to structure the debate among stakeholders (Pahl-Wostl, 2007; Voinov & Bousquet, 2010). In this respect, those

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involved in IWRM need to "learn to manage by managing to learn" (Pahl-Wostl, 2007). To support this process, this study presents a spatial integrated assessment (IA) approach following three steps:

1. Identify key indicators for sustainable development and their interdependence
2. Identify knowledge gaps in the system dynamics of the entire socio-ecological system
3. Address these knowledge gaps by gathering specific information.

The approach is illustrated by the case of the Lake Naivasha basin in Kenya. In this basin there is no lack of stakeholder initiatives and meetings. However, the knowledge gaps are overwhelming. The area has experienced rapid population growth and strong economic development on the one hand and considerable environmental degradation on the other. Because so many things are going on in the same geographical space simultaneously, this case serves as a good example for spatial IA. Following a case-study description, key indicators for sustainable development are presented. Then, knowledge that has emerged from the socio-economics, hydrology and ecology disciplines is summarized into knowledge gaps. Then, the proposed spatial IA approach, based on a joint effort by stakeholders and scientists, is presented and discussed.

The Lake Naivasha basin

The Lake Naivasha basin (Figure 1) simultaneously supports a wetland of international importance for biodiversity conservation (Ramsar, 2013) and a national economic hot spot. Exports of cut flowers have tremendously increased levels of employment and economic production. Water demands by the horticultural sector and the growing population have recently increased substantially (Van Oel et al., 2013), while at the same time land-use changes have affected the water balance and put the ecosystem under pressure (Otiang'a-Owiti & Oswe, 2007). Consequently, a wicked-problem situation has developed, with conflicting interests between stakeholder groups, including landowners, water users, pastoralists, fishermen and tourist and conservation organizations. These

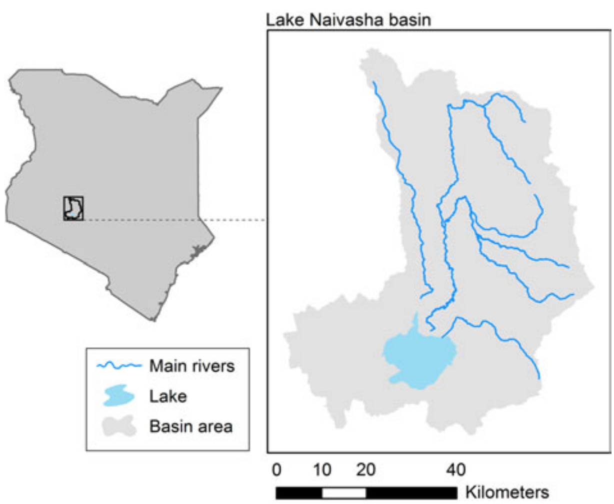

Figure 1. Lake Naivasha basin and its main rivers.

stakeholders disagree on the responsibility for addressing the problems (Becht, Odada, & Higgins, 2005). Factual disagreements also exist due to poor availability of information. Decision makers lack accurate and timely data, such as time series on meteorological parameters, runoff and water abstraction. This lack has hampered the development and enforcement of rules and regulations (WRMA, 2010).

Following a period of low lake water levels in 2009 and 2010 it became clear that the pressures affecting the ecosystem could lead to severe water stress (Van Oel et al., 2013) and poor water quality, leading to fish dying (Mutia et al., 2012). This raised a general sense of urgency concerning the need for additional knowledge on how to secure a sustainable future for the Lake Naivasha basin. In response, both international NGOs (AWS, 2011; WWF, 2011) and academic researchers contributed to produce a rich collection of knowledge captured in literature. Still, knowledge generated is not necessarily useful and it is not always possible to support actual interventions with sound evidence in a timely fashion. Thus, there seems to be a mismatch between the scope of academic efforts and requirements for knowledge generation in order to be able to implement IWRM practices. Moreover, although in recent years the need for community participation and consensus building has been acknowledged (Becht et al., 2005; WRMA, 2010), there still is a serious “lack of compliance and enforcement” regarding water-related policy (WRMA, 2010). Therefore, despite considerable effort, progress towards sustainable management of the Lake Naivasha basin has been limited (Harper, Morrison, Macharia, Mavuti, & Upton, 2011).

Key indicators for sustainable development and their interdependence

Supported by an intensive stakeholder process in the period 2009–2013 (see the appendix) the following indicators have been identified as key for sustainable development of the Lake Naivasha basin.

- Eco-hydrological indicators: water availability (in streams, aquifers and the lake), water quality (with a focus on turbidity), and flora and fauna richness and abundance (including the fish population in Lake Naivasha)
- Economic indicators: production and employment
- Social indicators: poverty alleviation and equity

These indicators are spatially explicit, and knowledge of their interdependencies reflects possible conflicting interests. Interventions by those involved in water governance should aim at manipulating the system in such a way that the indicators are affected as desired. But this can only be achieved when decision makers can both anticipate the effect of interventions (policies) and enforce operational rules. The interdependence between these indicators is presented in Figure 2.

Knowledge gaps in the system dynamics of the entire socio-ecological system

The knowledge available from three traditional scientific disciplines is described in the following three subsections. After this, the knowledge gaps considered the most relevant in the light of Figure 2 are presented.

Knowledge of the socio-economic subsystem

Economic growth in general and job opportunities in the horticultural sector in particular have been major drivers of population growth in the Lake Naivasha basin (Mulatu, Van der Veen, Becht, Van Oel, & Bekalo, 2013). The human population in the basin has

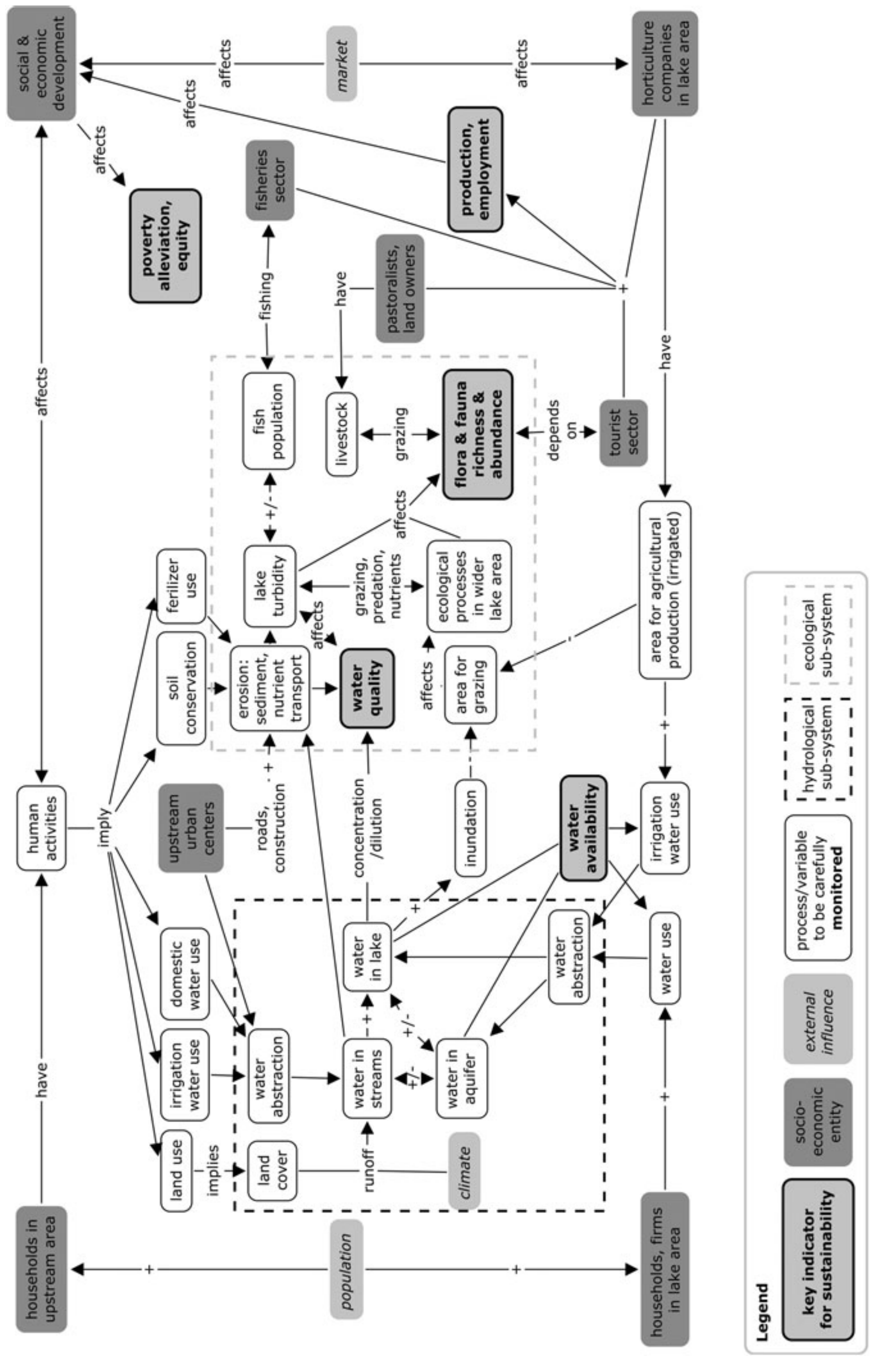

Figure 2. Schematization of key indicators for sustainable development, other variables to be carefully monitored, socio-economic entities and external processes, and important links between them.

increased, from around 250,000 in 1980 to over 600,000 in 2009 (KNBS, 2009). Population growth and socio-economic developments have contributed to the degradation of the lake and the lakeshore close to informal settlements (Harper & Mavuti, 2004). Other effects include increased water abstractions (Van Oel et al., 2013) and land-use changes that have amplified fluxes of nutrients and sediments into Lake Naivasha (Stoof-Leichsenring, Junginger, Olaka, Tiedemann, & Trauth, 2011; Verschuren, 1999). On the other hand, the socio-economic system also depends on the ecosystem services offered by the Lake Naivasha basin. Especially the horticultural sector is contingent on the basin water for irrigation (Van Oel et al., 2013). Fisheries depend on lake water quality, and the tourism sector depends on the natural beauty of the area. These three sectors together constitute the larger share of the local Naivasha economy on which the majority of the population depends.

Most studies describing socio-economic activities focus on environmental degradation caused by human activities. Some studies discuss management alternatives that take into account both the environment and the economy (e.g. Ellis-Jones, 2007; Mekonnen, Hoekstra, & Becht, 2012); but the effect of policy interventions is not easily estimated for lack of data on socio-economic indicators at relevant spatial levels. Partly due to this lack of data, little is known on the importance of the environment to both the local economy and individual livelihoods.

Knowledge of the hydrological subsystem

The water balance of the Lake Naivasha basin has been described and discussed in a number of studies (e.g. Åse, Sernbo, & Syrén, 1986; Becht & Harper, 2002; Gaudet & Melack, 1981). These studies have largely focused on the water budget of the lake rather than on understanding basin-level hydrological processes. Because there is a considerable amount of exchange between surface water and groundwater, groundwater hydrology is highly relevant for describing the water budget of Lake Naivasha (Van Oel et al., 2013). There is net outflow from the aquifer around Lake Naivasha, for which estimates vary (e.g. Clarke, Goodhall, Allen, & Darling, 1990; Ojiambo, Poreda, & Lyons, 2001). Large uncertainties and gaps are associated with the available data-sets for rainfall, discharges, evapotranspiration, groundwater levels, land use and water abstraction. The effect of water abstractions on lake volumes has been estimated (Van Oel et al., 2013) but the difference between the effects of abstraction from groundwater and surface water is unclear. With regard to surface hydrology, the effects of land-use changes and climatic variability on the water balance are also unclear.

Knowledge of the ecological subsystem

Lake Naivasha transformed from a clear to a turbid lake years ago (Harper, Mavuti, & Muchiri, 1990). Influenced by both natural and human processes, the spatiotemporal distribution of turbidity levels in Lake Naivasha varies (Ndungu et al., 2013). The major drivers of turbidity are the introduction of alien species and physical-chemical degradation (Gherardi et al., 2011). Physical-chemical degradation is affected by the inflow of runoff, nutrients and sediments (Harper & Mavuti, 2004; Kitaka, Harper, & Mavuti, 2002), lake volume changes, and seasonal differences affecting ecological processes. Lake Naivasha's exclusively exotic fish population (Gherardi et al., 2011) also affects and is affected by turbidity (Britton & Harper, 2006; Gherardi et al., 2011; Hickley et al., 2004; Mavuti, 1990). Although many characteristics of Lake Naivasha's aquatic ecological system have been described in the literature, the internal turbidity dynamics and therefore the lake's responses to perturbations and interventions remain largely unknown.

Descriptions of the Lake Naivasha ecosystem include those of Gaudet (1977, 1979), Gaudet and Muthuri (1981), and Morrison and Harper (2009). A major focus of these studies is the importance of the wetland system for lake water quality, with a particular emphasis on the influence of *Cyperus papyrus* on nutrient and sediment balances. To understand the importance of the Lake Naivasha wetland to the wider ecological system, there is a need to shift attention to the roles of biotic and abiotic processes that regulate the ecosystem's productivity and species diversity (Muthoni, Groen, Skidmore, & Van Oel, 2014). Thus far no spatially explicit analysis has been undertaken to understand the mechanisms that regulate the productivity and species diversity in the wider area surrounding Lake Naivasha.

Identified knowledge gaps

From the three previous sections, four major knowledge gaps have been identified and translated into four questions.

1. How does the socio-economic subsystem depend on the ecological system (ecosystem services)?. The available literature on the socio-economic subsystem is biased towards environmental problems caused by socio-economic developments. The functions and value of the environment for various sectors (e.g. in terms of ecosystem services) are under-evaluated. Particularly if one is to implement market mechanisms for sustainable governance of the basin ecosystem—e.g. water pricing, or payment for ecosystem services (PES)—this kind of knowledge is badly needed.

2. What are the influences of water use and land use on water availability?. The relatively abundant knowledge on the hydrological subsystem is biased towards the most visible part of the water balance: Lake Naivasha. The effects of abstractions from groundwater and exchange between groundwater and surface water are largely unknown. Also, the influences of land-use changes and water abstractions in the wider basin area are not very well understood.
3. What are the (human) causes of the eutrophic state (turbidity) of Lake Naivasha?. A reconstruction of events (e.g. blooms, invasive species, and general turbidity increase) can be made from the available literature. However, this is not quite sufficient for evaluating the impact of perturbations and the effectiveness of interventions.
4. How does the terrestrial ecosystem (biodiversity) depend on the water balance?. Though much attention has been devoted to studying the importance of the Lake Naivasha fringe for the lake itself, little is known about the importance of the lake system for the entire ecosystem.

Addressing knowledge gaps through spatial integrated assessment

For the present situation in the Lake Naivasha basin, studying hydrological processes does not make much sense without considering land-use changes and water abstractions. Also, the dramatic changes with regard to aquatic and terrestrial ecology in recent decades cannot be understood without considering external perturbations, including the increased influx of sediment and nutrients and the introduction of alien species. On the other hand, the socio-economic structure of the Lake Naivasha basin community also strongly depends on the state of the natural environment by means of the ecosystem services it provides. The emergence of institutions, including collective action, is influenced by the states of both the natural and the social environment (Willy & Holm-Müller, 2013). Local circumstances and differences in resource availability between upstream and downstream parts of the river basin may lead to collective action and influence willingness to pay and acceptance by participants of PES schemes. To capture the complexities related to human–environment interactions, agent-based modelling could be applied (An, 2012; Torrens, 2010). Examples of how to apply agent-based modelling to water resources use and management include Berger, Birner, Diaz, Díaz, and Wittmer (2007) and Van Oel, Krol, and Hoekstra (2012). For this IA study of the Lake Naivasha basin, some preliminary results are available (Van Oel & Van der Veen, 2011). When performing a spatial IA in a socio-ecological system one needs to incorporate the spatial complexity of the relevant processes. Because many systems are linked by their geographical overlap, geographical information is of particular importance in integration and interdisciplinary research. In Table 1, the most relevant aspects of the subsystems covered in this study are summarized. An impression of the different types of fieldwork sampling locations is given in Figure 3. Detailed field studies have been performed that allow outreach from the traditional scientific disciplines to support IWRM. This multidisciplinary approach includes reducing uncertainties in the factual knowledge base for IWRM by analyzing historical spatiotemporal data. A preliminary outcome of this effort is described by Odongo et al. (2014). The following sections decribe outreach from the traditional scientific disciplines in more detail.

Outreach from the socio-economic subsystem to address Knowledge Gap 1

The Lake Naivasha basin is a relatively data-poor environment, especially when it comes to socio-economic information. Therefore, the use of earth observation (EO) as an additional resource is explored. As a first step, the spatial relationship between population density and land-use and land-cover changes has been explored using a series of remote-sensing data for the period 1973–2011 (Mulatu et al., 2013; Odongo et al., 2014). To understand the socio-economic subsystem, market-based approaches (i.e. PES) are currently being evaluated. A choice experiment for environmental valuation was used to assess the preferences of the upstream households to improve ecosystem services (Mulatu, Van der Veen, & Van Oel, 2014). Also, the preferences of socio-economic agents around the lake (i.e. fishermen, firms and farms) are being explored. This approach will give insight into links between the environment and the economy.

Outreach from the hydrological subsystem to address Knowledge Gap 2

This work addresses human influence (water abstractions, land use, land management) on the hydrologic system. In addition to a hydrological process-based approach being developed (Meins, 2013), impacts of land-use changes (Odongo et al., 2014) and soil loss (Odongo, Onyando, Mutua, Van Oel, & Becht, 2013) have been investigated. EO techniques, household surveys and hydrological models were employed to enhance our understanding of the entire hydrological system, including the groundwater system (Hogeboom, 2013; Odongo et al., 2014).

Outreach from the ecological subsystem to address Knowledge Gaps 3 and 4

With regard to the aquatic ecological system, the use of EO for monitoring chlorophyll *a* and total suspended solids was explored using weekly to bi-weekly ground measurements

Table 1. Characteristics of the subsystems (scientific disciplines).

Knowledge gap addressed	Main processes	Spatial scale	Main social agents	Integrated assessment indicator(s)
Socio-economic system How does the socio-economic system depend on the ecological system (ecosystem services)?	Water use	*Extent:* basin	Rural households; urban centres and companies; water user collectives; fishermen, pastoralists; tourist sector	Employment
	Land use	*Resolution:* land use (ha), communities (ha–km2)	Landowners	Production
	Fertilizer use Soil and water conservation efforts			
Hydrological system What are the influences of water use and land use on water availability?	Rainfall, runoff	*Extent:* basin	Rural households	Water availability in streams, aquifer and lake
	Water balance	*Resolution:* land cover (~ ha), sub-basins (~100 km2)	Urban centres and companies	
	Erosion Sediment, nutrients			
Aquatic ecological system What are the human causes of the eutrophic state (turbidity) of Lake Naivasha?	Hydraulics	*Extent:* lake and riparian zone	Fishermen	Water quality
	Sedimentation	*Resolution:* lake zones (km2)		
	Turbidity dynamics		Urban centres	Fish abundance
Terrestrial ecological system How does the terrestrial ecosystem (biodiversity) depend on the water balance?	Water balance	*Extent:* riparian zone and wider lake area	Pastoralists	Species richness
	Inundation	*Resolution:* lake level fluctuations (cm/ha)	Tourist sector	
	Nutrient balance		Landowners	Species abundance

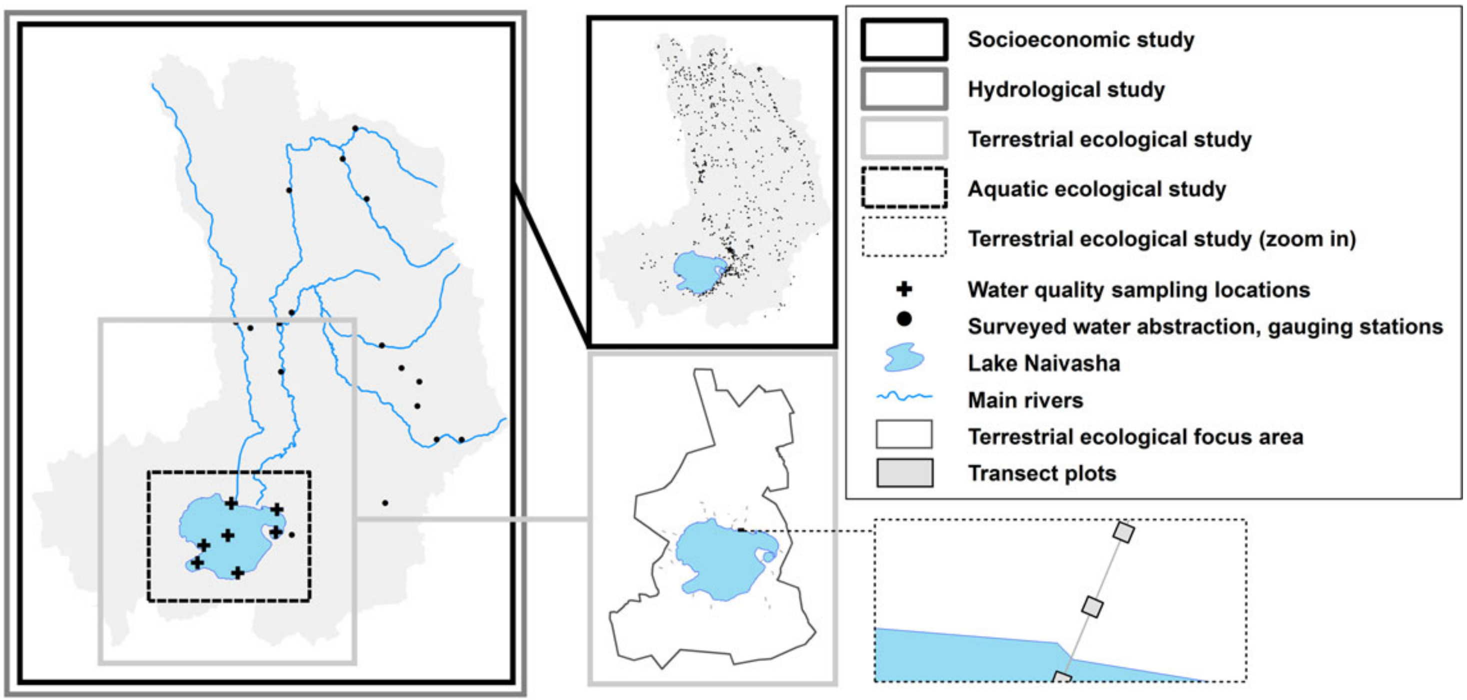

Figure 3. Fieldwork locations for the different focus disciplines of this study: for the hydrological system, discharge measurement stations; for the aquatic ecological system, water quality sampling sites; for the terrestrial ecological system, transects along the lakeshore; for the socio-economic system, water abstraction locations.

of chlorophyll *a* and total suspended solids taken in year 2011 (Ndungu et al., 2013). By studying the lake system in a spatially explicit way, the linkages to the hydrological, terrestrial ecological and socio-economic subsystems become more apparent. In studying the terrestrial ecology around Lake Naivasha, extensive use is made of EO techniques. Using plot measurements of productivity and enclosure experiments, system dynamics were studied in great detail (Muthoni et al., 2014). Remote-sensing data are further used to make spatiotemporally explicit estimates of plant species diversity in the ecosystem.

Discussion and conclusion

This study demonstrates how efforts by both local stakeholders and researchers have so far inadequately addressed IWRM-related wicked problems in the case of the Lake Naivasha basin, Kenya. The knowledge base currently available to local stakeholders is insufficient to implement IWRM in the way stakeholders would like, and at the same time local stakeholders are not collecting the data required to overcome this. Unfortunately, scientists have mostly failed to tune their research focus to stakeholder needs. In their efforts to produce cutting-edge research findings they tend to lean towards their own scientific disciplines rather than aiming at filling the knowledge gaps hampering local IWRM implementation. Moreover, scientists are generally not sufficiently motivated to communicate their findings outside their own scientific disciplines. Ideally, scientific efforts to improve IWRM should address knowledge gaps together with stakeholders. To improve IWRM, the joint identification of key indicators for sustainable development, and their interdependencies, and knowledge gaps is an important first step. This should lead to the building blocks of a structured debate that could substantially contribute to the implementation of IWRM.

A detailed analysis of available (disciplinary) knowledge is needed to account for different perspectives. Also, one needs to incorporate the spatial complexity of the most relevant processes. Because many systems are linked by their geographical overlap, geographical information is of particular importance for integration and interdisciplinary research. With regard to the wicked problems that IWRM generally aims to address, some argue that no experts on these problems can exist (Ludwig, 2001). For this reason it is very important to maintain a dialogue among all interested parties, including academic researchers. From the bottom up, many initiatives have emerged over the years in which local users have collectively pursued initiatives relevant to water governance. Local initiatives mostly focus on the collective interest at the scale of local resources (e.g. the lake or water projects). Collective activities include the ongoing work coordinated by the Imarisha Naivasha board and the Kenya Country Office of the World Wide Fund for Nature, following initiatives by the office of the prime minister of Kenya in 2012 (Imarisha Naivasha Trust, 2012) and the embassy of the Kingdom of the Netherlands (IWRAP, 2012), respectively.

It is further argued that even when detailed disciplinary studies are required, researchers should still keep track of the significant dependence on factors outside the discipline. However, efforts towards achieving sustainability in relation to the Lake Naivasha basin, including establishing sound and fair water allocation plans, have been found to be seriously hampered by the lack of some of the most relevant knowledge. And even if abundant relevant knowledge should become available and the major knowledge gaps be sufficiently addressed, underlying conflicting interests will still remain.

Proposed interventions such as PES programmes (Mulatu et al., 2014), possibly including the introduction of a water footprint premium (Mekonnen et al., 2012), are potentially powerful tools for implementing IWRM. However, further study is needed to adequately quantify how effective they could really become. Next, for these tools to be effectively implemented, a sophisticated monitoring system should be in place and commitment to rules should be enforced. Despite recent efforts (IWRAP, 2012), the limited availability of reliable and timely information in the case of the Lake Naivasha basin is not likely to be overcome in the near future unless major additional investments are made.

Acknowledgements

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Appendix: Stakeholder processes in the Lake Naivasha basin

Stakeholders' participation in water resources management in Kenya, and the Lake Naivasha basin as such, is institutionalized in the Water Act of 2002, which defines the management, conservation, use and control of water resources. The act not only emphasizes decentralization and subsidiarity but also creates a new institutional design that allows the engagement of government and non-government entities in the management of water resources through public-private-people (civil society) partnership. Leading the stakeholders are government organizations, including ministries and parastatals, that have the mandate and responsibility to manage natural resources. At the centre of government institutions in the Lake Naivasha basin is the Water Resources Management Authority (WRMA), Naivasha subregional office, which has the overall mandate to conserve, manage and regulate the use of water resources. In addition, the legislation provides for the creation of water resource user associations (WRUAs). There are a total of 12 WRUAs in the basin, each collaborating with the WRMA. The WRUAs represent water users in a subcatchment area. The creation of WRUAs provides a bottom-up perspective and a deviation from the previous government-centred initiatives.

The Imarisha Naivasha programme, a government outfit supported by the Prince of Wales' International Sustainability Unit, provides a forum for coordination of management activities and collective engagement by the stakeholders involved in the conservation of the lake and its catchment. The board of Imarisha Naivasha includes representatives from public-sector, private-sector and community organizations. The programme has, in consultation with other stakeholders, developed a Lake Naivasha basin Sustainable Development Action Plan for 2012–2017 to guide in the restoration of the ecosystem functions, biodiversity and natural attractions of the Lake Naivasha basin. Further, the stakeholders have developed a Lake Naivasha Integrated Management Plan for 2012–2017. The plan offers an integrated, coordinated, stakeholder-focused approach to the planning, management and monitoring of developments within the basin, seeking equitable, efficient and environmentally sound solutions for the benefit of the entire community within the basin.

Non-governmental stakeholder participation in the basin's management finds its origin in the Lake Naivasha Riparian Association, the oldest institution in the basin (it was founded in 1929). Most of the private-sector organizations are engaged in water resources management due to the commercial gains expected from the resources, e.g. the flower farms around the lake, which are mostly represented through their umbrella organization, the Lake Naivasha Growers Group (LNGG). International NGOs and donors have strongly participated in the basin's management through projects aimed at supporting the capacity of institutions and local resource user groups. WWF-Kenya and CARE-Kenya have been involved in coordination as intermediary institutions in a PES scheme for market-based approach to delivery of sustainable natural resource management and improved livelihoods. This is done through the involvement of the WRMA, the LNGG and the WRUAs. Through funding from the embassy of the Kingdom of the Netherlands, the Integrated Water Resource Action Plan (IWRAP, 2012) brings together various public and private partners from Kenya and the Netherlands on sustainable land and water management for people, businesses and nature in the Lake Naivasha basin.

Over the years, several research organizations have actively participated in the basin. These include the University of Twente, University of Nairobi, Egerton University, Leicester University, University of Bonn, University of Ghent and University of Western Ontario. Notable is the Earth Observation and Integrated Assessment project, in which the University of Twente, University of Nairobi and Egerton University collaborate with stakeholder organizations and other research organizations in the basin. This 5-year project focuses on how earth observation and derivative geo-information may be instrumental in overcoming water-related societal clashes in a collaborative stakeholder setup. The project has held annual stakeholder meetings and workshops from 2009 to 2013. Methods applied included scenario building through forecasting and back-casting and participatory mapping exercises. Thus were the key indicators for sustainable development identified as presented in the main text of the article.