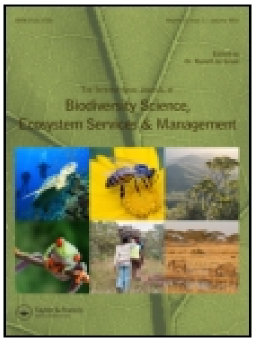

International Journal of Biodiversity Science, Ecosystem Services & Management

ISSN: 2151-3732 (Print) 2151-3740 (Online) Journal homepage: http://www.tandfonline.com/loi/tbsm21

Green Water Credits – exploring its potential to enhance ecosystem services by reducing soil erosion in the Upper Tana basin, Kenya

Sjef Kauffman, Peter Droogers, Johannes Hunink, Boniface Mwaniki, Fred Muchena, Patrick Gicheru, Prem Bindraban, Davies Onduru, Rudolph Cleveringa & Johan Bouma

To cite this article: Sjef Kauffman, Peter Droogers, Johannes Hunink, Boniface Mwaniki, Fred Muchena, Patrick Gicheru, Prem Bindraban, Davies Onduru, Rudolph Cleveringa & Johan Bouma (2014) Green Water Credits – exploring its potential to enhance ecosystem services by reducing soil erosion in the Upper Tana basin, Kenya, International Journal of Biodiversity Science, Ecosystem Services & Management, 10:2, 133-143, DOI: 10.1080/21513732.2014.890670

To link to this article: http://dx.doi.org/10.1080/21513732.2014.890670

International Journal of Biodiversity Science, Ecosystem Services & Management, 2014
Vol. 10, No. 2, 133–143, http://dx.doi.org/10.1080/21513732.2014.890670

Green Water Credits – exploring its potential to enhance ecosystem services by reducing soil erosion in the Upper Tana basin, Kenya

Sjef Kauffman[a], Peter Droogers[b], Johannes Hunink[b,*], Boniface Mwaniki[c], Fred Muchena[d], Patrick Gicheru[e], Prem Bindraban[a], Davies Onduru[d], Rudolph Cleveringa[f] and Johan Bouma[g]

[a]*ISRIC – World Soil Information, PO Box 353, 6700AJ Wageningen, The Netherlands;* [b]*FutureWater, Costerweg 1V, 6702AA Wageningen, The Netherlands;* [c]*Water Resources Management Authority, Embu, Kenya;* [d]*ETC – East Africa, ABC Place, Waiyaki Way, PO Box 76378, Nairobi, Kenya;* [e]*Kenya Agricultural Research Institute, Waiyaki Way, Nairobi, Kenya;* [f]*International Fund for Agricultural Development, Via Paolo di Dono, 4400142 Rome, Italy;* [g]*Formerly Soils Department Wageningen University, Droevendaalsesteeg 4, 6708 PB Wageningen, The Netherlands*

Food production, water availability and energy production are important ecosystem services of the Upper Tana basin (Kenya) and they decline due to upstream erosion affecting downstream water users. The effect of 11 soil conservation measures on soil erosion and the three ecosystem services was estimated by a modelling approach to assess agro-ecological processes and benefit/cost relations. Soil water available for evaporation and transpiration ('green water') functioned as a unifying concept to express the effects of erosion and the impacts of soil and water conservation measures that result in: (1) increased water availability for crops; (2) increased fluxes towards aquifers, thereby increasing water supply and regulating streamflow, and (3) a reduction of erosion and siltation of reservoirs used for hydroelectricity. Modelling indicated that the three ecosystem services could be improved, as compared with the base level, by up to 20% by introducing appropriate conservation measures with benefit/cost relations of around 7. However, farmers were unable to make the necessary investments and much effort and many institutional studies were needed to achieve progress towards implementation by initiating the Green Water Credits (GWC) programme intended to arrange payments by downstream businesses to upstream farmers. A timeline analysis is presented to illustrate the slow, but persistent, development of transdisciplinary activities as a function of time using *connected value development* as a guiding principle.

Keywords: rural development; green water management; soil and water conservation; transdisciplinarity

1. Introduction

Ecosystem services, defined as 'benefits people obtain from ecosystems', are a valuable concept for ecosystem studies. By defining four types of services in terms of *supporting, provisioning, regulating and cultural* functions, attention is focused on a wide range of interlinked ecosystem functions requiring an inter- and transdisciplinary research approach (Millennium Ecosystem Assessment 2005; www.teebweb.org/resources/ecosystem-services). Many studies on this concept have already been made. For example, De Fries et al. (2004) studied aspects of land use. Guo et al. (2000) considered effects of flow regulation on hydroelectric power. Ojea (2010) studied forest water services. Daniel et al. (2012) and Tengberg et al. (2012) assessed effects of cultural services and Kremen (2005] explored ecological aspects. Grieg-Gran et al. (2006) analysed ecosystem services in the context of this study. Hanson et al. (2012) synthesized a wide variety of research efforts by presenting business-oriented guidelines to allow the systematic implementation of an ecosystem service methodology. These guidelines were followed in this study in the Tana catchment in Kenya that provides a series of ecosystem services, of which food production, water availability and energy production, acting as *provisioning services,* are most important. Carbon sequestration by avoiding soil erosion is also relevant as a *regulating service.* General preservation of the natural landscape can be seen as a *cultural service* (e.g. Egoh et al. 2012; Tengberg et al. 2012). An important problem is continuing erosion in the upstream areas leading to a general decline of all services. How to reverse this process and embed the services within an operational setting constitutes the main challenge to be discussed in this paper, considering three elements.

First, reducing erosion and improving water management in farm and rangeland is not a simple technical matter, but has complex socio-economic implications. The threats of soil erosion have been well documented in literature for decades, demonstrating serious problems, e.g. food and water security, climate change, energy sustainability and biodiversity protection, thus constituting a significant barrier to sustainable development (e.g. JRC-EEA 2010; Banwart 2011; Food and Agricultural Organization 2011). Also, data documenting soil degradation by erosion and predicting its effects by modelling have been available for decades, but many declarations and proposed programmes of action have not significantly resulted in increased public awareness or effective political action, let alone in broad implementation of conservation measures by farmers (e.g. Hurni et al. 2006; United Nations Environment Programme 2007; United

*Corresponding author. Email: j.hunink@futurewater.es

Nations 2010). In fact, the World Overview of Conservation Approaches and Technologies (WOCAT) database (World Overview of Conservation Approaches and Technologies 2007) lists well-tested and successful methodologies to combat erosion and improve water management in farm and rangeland for a wide range of environmental conditions, showing that the knowledge is available to solve the problem. But the methods are not widely applied in practice, because farmers are not willing or able to make substantial short-term investments that, at best, only provide long-term dividends. Considering that emphasis on erosion, as such, appears to have been less effective in the past in terms of producing concrete action, this paper will frame soil erosion and water management in terms of its effect on ecosystem services, expecting that this will improve communication with both stakeholders, business partners and policy-makers.

Second, when trying to improve ecosystem services, it is not enough to run quantitative scenario assessments illustrating potential gains of introducing soil conservation measures. If the suggested methodology is not supported by a solid financial investment scheme, chances for uptake are very low. To overcome such problems, Payment for Ecosystem Services (PES) has been proposed and successfully tested in Asia and South America as a method to facilitate implementation of soil conservation measures (e.g. Pagiola et al. 2005; Wunder 2005; Schomers & Matzdorf 2013). Also, in Africa, a few PES programmes have been started and evaluated (Porras et al. 2008). Land users receive investment support for practices that have environmental value beyond the direct commercial interests of the land users themselves. The PES concept is particularly relevant for soil erosion, as downstream effects may be quite serious not only for land users but also for hydroelectricity and water companies that are confronted with rapid siltation of their reservoirs. PES for upstream farmers could be instrumental in convincing them to take conservation measures. In this study, the Green Water Credits (GWC) approach will be presented as an example of a PES scheme focused on the effects of soil erosion.

Third, even a well-developed, financially sound, investment plan on paper, which has been embraced by the stakeholders involved, may not result in practical implementation when the various stakeholders are, after all, not convinced that they are the real ‘owners’ of the plan. Bouma, Van Altvorst, et al. (2011) described studies on sustainable agriculture in the Netherlands, in which successful implementation could only be achieved when the various stakeholders were involved in an intensive co-learning mode right from the start of the programme. Procedures were complex and time-consuming.

In summary, the objectives of this study are to: (1) explore, using quantitative modelling techniques, how the decline of ecosystem services due to erosion in the Upper Tana basin can be reversed by proper soil conservation measures; (2) explore the potential of a GWC-based programme to implement proper soil and water conservation measures by developing a business case that expresses benefits versus costs; and (3) assess the role of the generated biophysical and financial data in realizing an effective transdisciplinary research approach that results in a specific plan, which is embraced by all stakeholders involved.

2. Materials and methods

2.1. The Upper Tana Basin, Kenya

The Upper Tana Basin in Kenya (Figure 1) faces severe challenges to meet increasing water demands due to poverty and population growth (Githui et al. 2009). The basin is of strategic importance for the water and energy supply of the country. The Tana River is relatively rich in water, as compared to other rivers in the country, and receives its

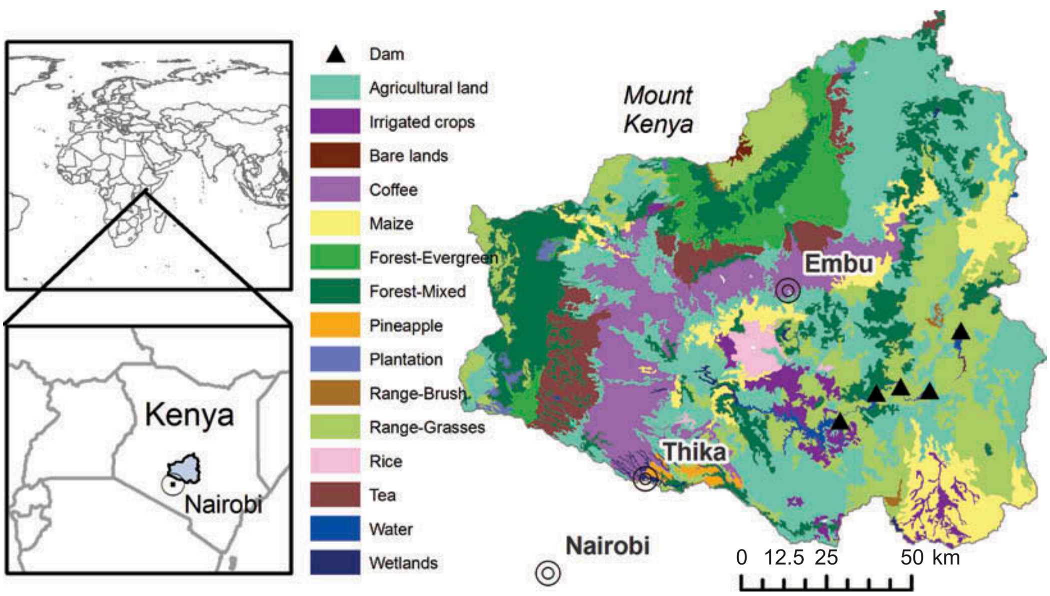

Figure 1. Location of the Tana River basin, reservoirs and land use.

water from two main sources, Mount Kenya and the Aberdares Range. In the past century, farmers occupied the Tana upstream land area, altering the water balance of the basin by clearing the natural vegetation for agriculture, reducing downstream water availability, increasing soil erosion and sedimentation of reservoirs (Hunink et al. 2013). The main crops are maize, coffee and tea (Figure 1), but flowers, horticulture and fruits are also produced for the international market. Livestock farming systems occur in the lower reaches of the watershed into the drier areas. Water downstream is used for hydropower, irrigation, industrial and domestic use in the capital Nairobi, creating a high downstream dependency on the quality of upstream soil and water management. Rainfall is mainly a function of elevation, with conditions ranging from humid at high altitudes to semi-arid at lower elevations of the middle and lower Tana. Downstream, five major reservoirs have been built for hydropower and flow regulation. Two smaller upstream reservoirs are used for water supply of Nairobi. Population growth in recent years has caused a steady increase in water and electricity demand, both upstream and downstream. Recent severe droughts made it even necessary to ration water and electricity. The high sediment loads cause high treatment costs to the water supply companies and maintenance costs to hydropower companies which were actively involved in the GWC. Also, loss of storage capacity of the downstream reservoirs threatens their usefulness in the long term (Hunink et al. 2013).

2.2. Green water credit as a form of payment for ecosystem services (PES)

Green water refers to water held in (unsaturated) soil above the groundwater table, available for transpiration and evaporation, while blue water refers to surface- and groundwater in aquifers, rivers and other water bodies (Falkenmark 1995). The GWC approach involves investment support for farmers in a watershed to increase their quantity of green water by improving their soil and water management, reducing erosion, the associated surface run-off and soil evaporation. This, in turn, leads to increased rainwater infiltration into the rootable soil (increasing the volume of *green water*) and some of it moving into the aquifer below (increasing the volume of *blue water*), and thus an increase of groundwater recharge. These processes are beneficial for downstream water users by: (1) replenishing the groundwater aquifer, (2) reducing river peak flows, because of reduced surface run-off, thereby regulating river flow; (3) avoiding costly sedimentation of water reservoirs and reducing the intake of sediments into the pipe networks of hydropower plants and water supply systems. The latter two enterprises would therefore be in a position to contribute to investment support for farmers in a GWC scheme only if their long-term benefits would exceed the amount to be invested. Obviously, a solid business case has to be presented to convince reluctant downstream entrepreneurs to participate in a GWC scheme. Upstream farmers themselves may also benefit by higher crop yields resulting from higher available water and lower losses of fertile topsoil by erosion. Downstream blue water benefits include extended periods of river flow and higher ground water tables. The GWC approach physically connects stakeholders, within a watershed, who may not even be aware of each other's existence, while they are in fact interdependent, as upstream land use practices directly or indirectly affect the downstream water users. GWC terminology has been coined as it points explicitly to landscape processes that land users can recognize. The term PES is, in contrast, rather abstract.

2.3. The modelling approach quantifying erosion and ecosystem services

Computer simulation models were used to quantify erosion processes as a function of land use as well as the associated ecosystem services. To preserve the spatial heterogeneity in the basin, this study made use of hydrological response units (HRUs) that allow splitting up the model domain in unique combinations of topography, soils and land use, preserving the spatial distribution of soils. The distributed hydrological model soil and water assessment tool (SWAT) (Neitsch et al. 2002) was used to quantify water fluxes in the 2226 HRUs. The study made use of large data sets in the public domain – Upper Tana World Soils and Terrain Database (SOTER) (Dijkshoorn et al. 2010), FAO Africover (www.africover.org, last accessed 29/8/2013) and Famine Early Warning Systems Network (FEWS-NET) (provided by the United States Climate Prediction Centre) – as well as locally sourced climate, soil and land use data sets. A considerable effort was made to improve the earlier Africover land use map. An improved land use map was made in 2009 based on satellite imagery interpretation backed up by field observations, also in 2009. A complete description of these data sets and the modelling approach can be found elsewhere (Hunink et al. 2011, 2012, 2013). Soil classification followed the Revised Legend of the Soil Map of the World (Food and Agricultural Organization 1998). The area is represented by 68 soil types. The SOTER database includes the total available water capacity of the soil (expressed as water held between 'field capacity' and 'wilting point') and rootable depth. So, pedological information is used to derive the soil physical data for the model (e.g. Bouma, Droogers, et al. 2011). The WOCAT land management database (World Overview of Conservation Approaches and Technologies 2007) and the Kenya Soil Survey were consulted to identify appropriate management practices to: (1) avoid soil degradation and erosion; (2) enhance infiltration and crop transpiration; and (3) reduce evaporation. Eleven practices were specifically defined for the agro-ecological conditions of the Upper Tana and they are associated with different crops, as indicated in Table 1. The Kenya Soil Survey delivered quantitative field-measured data on the beneficial effects of soil and water management practices.

Table 1. Modelled effects – percentages relative to the baseline – of different soil and water conservation scenarios on indicators related to green water, blue water and erosion. Values were calculated for relatively dry and wet years and cover different crops, as indicated (see text).

Scenario	Land use*	Year	Inflow Masinga MCM·y^{-1}	Sediment inflow Masinga Mt·y^{-1}	Crop transpiration mm·y^{-1}	Soil evaporation mm·y^{-1}	Groundwater recharge (basin) mm·y^{-1}	Erosion (basin) t·ha^{-1}·y^{-1}
Baseline		Dry	931	1.0	335	121	16	1.2
		Wet	2508	4.2	308	140	128	7.9
1 Bench terraces	MCT	Dry	1.1%	−21%	0%	−1%	3%	−23%
		Wet	1.9%	−21%	0%	0%	2%	−18%
2 Conservation tillage	M	Dry	0.1%	−1%	1%	−5%	1%	−2%
		Wet	0.1%	−1%	1%	−4%	0%	−1%
3 Contour tillage	M	Dry	1.1%	−10%	0%	−1%	7%	−12%
		Wet	0.8%	−7%	0%	0%	3%	−6%
4 Fanya Juu terraces	MCT	Dry	0.4%	−21%	1%	−1%	4%	−23%
and variations		Wet	1.3%	−20%	1%	0%	2%	−18%
5 Grass strips	MCT	Dry	0.6%	−11%	0%	−1%	3%	−14%
		Wet	0.6%	−10%	0%	0%	1%	−10%
6 Micro-catchments	MCT	Dry	0.6%	−8%	0%	−1%	2%	−8%
fruit trees		Wet	0.6%	−6%	0%	0%	1%	−5%
7 Mulching	MCT	Dry	0.4%	−6%	3%	−12%	3%	−9%
		Wet	0.5%	−6%	2%	−12%	2%	−8%
8 Rangelands	AR	Dry	0.1%	−4%	0%	−3%	1%	−4%
		Wet	0.0%	−2%	0%	−2%	0%	−6%
9 Ridging	M	Dry	1.4%	−18%	0%	−1%	23%	−21%
		Wet	1.0%	−12%	0%	−1%	10%	−12%
10 Riverine protection	MCTA	Dry	0.0%	−5%	0%	−1%	0%	−5%
		Wet	0.0%	−4%	0%	0%	0%	−4%
11 Trash lines	MCT	Dry	0.6%	−7%	0%	−3%	3%	−8%
		Wet	0.6%	−6%	1%	−2%	1%	−5%

Note: *M = Maize, C = Coffee, T = Tea, A = Agricultural arid and semi-arid, R = Rangelands.

2.4. *The modelling approach quantifying benefit/costs of soil conservation measures*

Results from the SWAT model were used to undertake a cost/benefit analysis. The Water Evaluation and Planning (WEAP) system was selected as the most appropriate tool (Droogers et al. 2011). WEAP places demand-side issues such as water use patterns, equipment performance, reuse strategies, costs and water allocation schemes on an equal footing with the supply-side aspects of streamflow, groundwater resources, reservoirs and water transfers. WEAP is also distinguished by its integrated approach to simulating both the natural (e.g. rainfall, evapotranspirative demands, run-off and base flow) and engineered components (e.g. reservoirs, groundwater pumping) of water systems. A detailed description of the model development and analysis can be found elsewhere (Droogers et al. 2011). In summary, the 11 GWC measures, as analysed using SWAT, were introduced into the WEAP model focusing on changes in: (1) rainfed crop transpiration; 2) stream flow; (3) inflow into reservoirs; and (4) erosion and sedimentation. The main output resulting from the WEAP analysis included: (1) rainfed agricultural production value; (2) irrigated agricultural production value; (iii) domestic water value; and (4) hydropower value.

2.5. *Getting the message across; the importance of transdisciplinary research*

Little of our research actually contributes to innovations and rural development, as is expressed by the 'knowledge paradox', which describes the fact that too much generated knowledge by research is never applied in the real world (e.g. Bouma 2010). Social scientists have thoroughly analysed these phenomena and propose a new *transdisciplinary* approach where interaction with various stakeholders, entrepreneurs and policy-makers plays a more important role. In fact, *transdisciplinarity* implies integration of science and development (Gibbons et al. 1994; Bunders et al. 2010). True *transdisciplinarity* can only be achieved if involved stakeholders (with often strongly contrasting views, visions and interests) somehow succeed in working together to achieve a common goal. Along these lines, 'communities of practice (CoP)' have been proposed by Wenger et al. (2002), in which scientists work together with stakeholders.

To underline the importance of this collaboration, which is crucial when considering livelihoods and rural development, the acronym KENGi-partners has been introduced (van Latesteijn & Andeweg 2011) to represent the major stakeholders in the *transdisciplinary* debate, where K stands for the Knowledge community, E for Enterprises and business, N for NGO's and civil-society organizations, G for government at different levels and i for system innovation that can only be achieved when these stakeholders somehow interact trying to first define and then reach a common goal. However, applications in practice are still limited and institutional, political, legal and emotional barriers all too often don't allow projects to achieve concrete results, if only because of time limitations. Genuine efforts to realize transdisciplinarity, all too often, get bogged down in terminology and procedural disputes as the 'hard' and 'soft' sciences operate from quite different perspectives. The case study in the Upper Tana basin will therefore be analysed in detail by the *connected value development* approach consisting of three phases: (1) *connected value proposition,* defining shared values, interests and goals based on developing a common language among the KENGi partners;(2) *connected value creation,* defining specific outlines of a potentially operational system; and (3) *connected value capture,* resulting in the concrete realization of the plans in practice (Bouma, Van Altvorst, et al. 2011). Case studies in the Netherlands showed that *capture* only occurred when highly dedicated and often idealistic stakeholder-groups (led by inspirational 'champions') are ready to face and overcome the overwhelming number of obstacles on the way to *capture.* In the Dutch case studies, entrepreneurs functioned as 'champions'. But they only could succeed when assisted by 'knowledge brokers' forming a liaison with the research community, providing the right type of knowledge at the right time and place and in the right way. Although the analysis showed significant financial and ecological benefits of soil conservation, much discussion was needed to convince the various stakeholders involved in this particular study. Special attention is therefore paid here to the interaction processes involved. In describing the development of the GWC concept in the Tana River basin, a timeline analysis will be followed, illustrating actions by the various KENGi partners as a function of time in analogy with Bouma, Van Altvorst, et al. (2011).

The KENGI approach can only be successful when adequate data are available. Aside from the biophysical and cost/benefit studies reported above, attention has been paid to: (1) an institutional survey analysing the supporting institutions and regulations that are needed for land users to improve their soil and water management practices; and: (2) a study on financial mechanisms allowing farmers to make investments, including collection and distribution of funds as well as monitoring and evaluation (reports at: www.greenwatercredits.org). These two studies are important in the *capture* process, which is in progress.

The *connected value development* procedure is central in the present study, but experiences and results will be compared with two recent reviews, covering key aspects of the Upper Tana Basin study. The comparison serves to put the study in a broader perspective. First, Sayer et al. (2013) distinguished 10 principles for decision-making when reconciling competing land uses: (1) need for continued learning and adaptive management; (2) entry point expressing a common concern; (3) consider multiple scales; (4) multifunctionality; (5) multiple stakeholders; (6) apply negotiated and transparent change logic; (7) classification of rights and responsibilities; (8) participatory and user-friendly monitoring; (9) resilience; and (10) strengthen stakeholder capacity. Second, Hanson et al. (2012) proposed five steps for identifying business risks and opportunities arising from ecosystem change and the associated services: (1) define the scope of the study, including physical boundaries of the study area; (2)identify priority ecosystem services; (3) analyse trends in priority services; (4) identify business risks and opportunities; and (5) develop an implementation strategy.

3. Results and discussion

3.1. The SWAT and WEAP analyses

Eleven soil conservation measures were characterized. Two results of the SWAT analysis for the area are shown as examples in Figures 2 and 3 and demonstrate the predicted reduction of erosion and the associated increase of groundwater recharge when applying ridging as a soil conservation measure. Similar spatial distributions were generated for the other 10 conservation measures, all showing high spatial diversity, which is important when planning and targeting measures in any given subarea. Results of the SWAT analyses are summarized in Table 1, which considers eleven soil conservation scenarios. Bench terraces and Fanya Juu terraces (with maize, coffee and tea) and ridging (maize only) are particularly effective in reducing both erosion and sediment inflow into the Masinga reservoir, all by approximately 20%. Conservation tillage (maize only) and mulching (maize, coffee and tea) have lower values of, approximately 1% and 6%, respectively, but here soil evaporation is reduced by 5% and 12%, respectively, thereby increasing the volume of *green water.* Ridging has the biggest effect on increasing groundwater recharge with 23% in dry years and 10% in wet years, while it also scores high for erosion and sediment inflow reduction.

Table 2 presents results of the cost/benefit analysis showing high values for Bench and, Fanya Juu terraces and Ridging varying between 5 and 7, illustrating the high

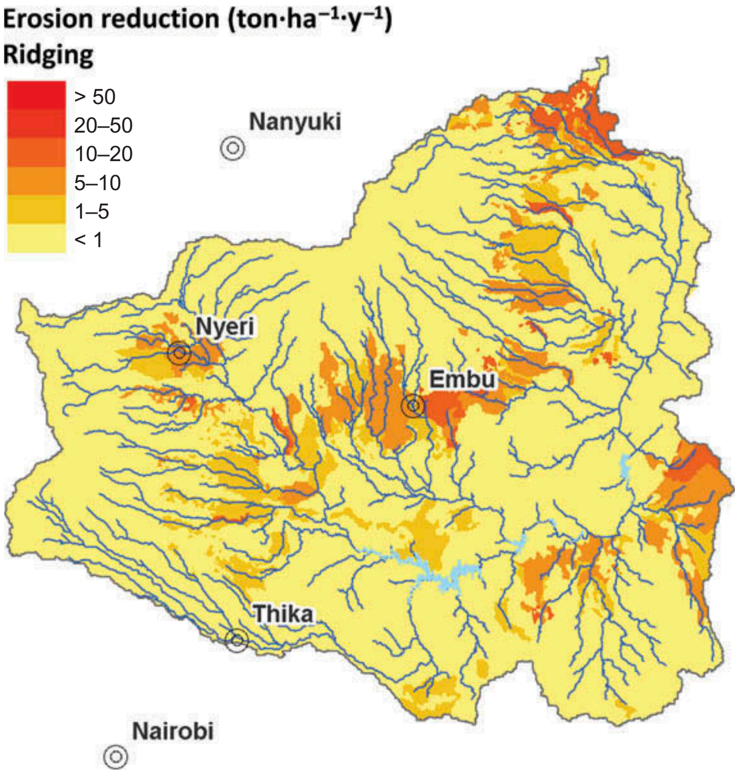

Figure 2. Spatial expression of predicted erosion reduction, as compared with the baseline scenario, following ridging.

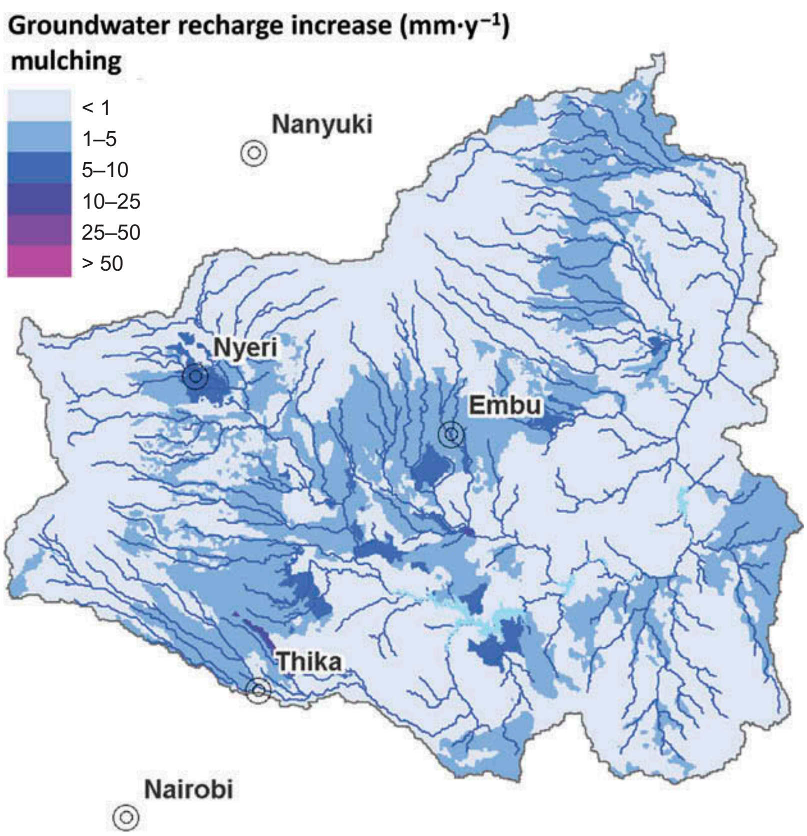

Figure 3. Spatial expression of the increase of recharge, as compared with the baseline scenario, following mulching.

Table 2. Benefit-cost analysis from the introduction of GWC scenarios based on the combined use of SWAT and WEAP analysis tools.

GWC scenario	Benefits – Costs ($mUS\$\cdot y^{-1}$)		
	Benefits	Costs	B-C
01_Bench	9.9	2.8	7.1
02_ConsTill	1.0	0.0	1.0
03_ContTill	4.9	0.0	4.9
04_FanyaJuu	9.0	3.7	5.3
05_GrassStrips	5.3	2.3	3.0
06_MicroCatch	1.6	0.1	1.5
07_Mulching	5.1	0.0	5.1
08_Rangelands	0.8	0.7	0.1
09_Ridging	8.9	1.6	7.3
10_Riverine	2.0	0.3	1.7
11_TrashLines	3.4	2.3	1.1

potential of the these conservation measures. Figure 4 extends the analysis by expressing financial benefits of each of the 11 measures for all partners involved in the GWC discussions. Potentially, according to these analyses, implementation of the GWC scenarios would have benefits that could go up to almost 10 million US$ annually. All these values turned out to be highly valuable in discussions with farmers and representatives of hydropower and water companies.

In addition to the ecosystem services being discussed, C-sequestration, a regulating ecosystem service, is also relevant here. Adoption of GWC practices can help restore soil organic matter levels to their natural or higher levels, contributing to CO_2 mitigation and enhanced agricultural production, as soils will have a higher water holding capacity. Carbon credits are an established form of PES and an *ex ante* assessment for the Upper Tana indicates a substantial potential financial source based on Carbon credits in the order of US$48-93X$10^6$ over a 20-year period (Batjes 2012).

The entire modelling analysis is based on a pragmatic application of the models rather than an in-depth model evaluation. However, a basic evaluation was undertaken for scientific rigour, showing that the models were able to predict streamflow accurately for various locations as compared with field measurements. Important here is that the focus of the analyses remained on the scenario approach, taking into consideration that 'relative' model accuracy (difference between baseline and various scenarios) is always higher than 'actual' model accuracy (difference between reality and model) (Droogers et al. 2008).

3.2. *Implications for the ecosystem services*

The SWAT analyses indicate a relatively low effect on the ecosystem service of food production, as indicated by the low gains (0–1%) for crop transpiration that are directly related to yield (Table 1). The accumulated long-term beneficial effects of soil and water conservation have not been taken into account in SWAT, because the analysis was concentrated on one dry and one wet year. Other studies provide numbers on the long-term beneficial effects related to yield (e.g. Mantel & Van Engelen 1999), which were used for the cost/benefit analysis with WEAP. The ecosystem service: water availability does, however, show clear effects of soil conservation. Groundwater recharge (following an increase of soil water infiltration and percolation) increases 23% (dry years) or 10% (wet years) when ridging is applied. Bench and Fanya terraces show a lower increase of approximately 3%. Contour tillage results in a 7% increase in dry years. The most important result from the study concerns sediment inflow into the Masinga reservoir, which has direct implications for two ecosystem services: water availability and energy supply, the latter in terms of electricity generation. Bench terraces and Fanya terraces reduce inflow by 20%, while ridging shows reductions of

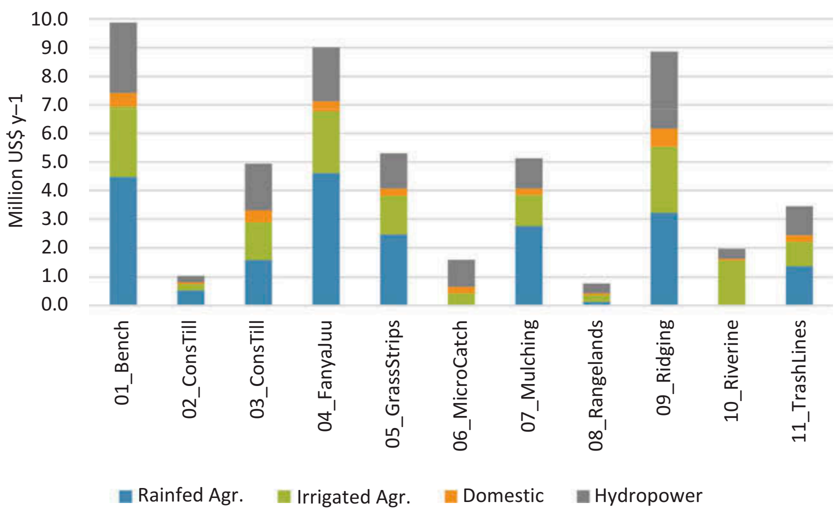

Figure 4. Total revenues (benefits minus costs) of implementation of the GWC scenarios for the four dominant water sectors (hydropower, domestic water supply and irrigated and rainfed agriculture).

18% in dry years and 12% in wet years. These results are highly relevant, as they indicate that sedimentation in reservoirs can be strongly reduced, which is of interest to water and electricity companies.

3.3. *Interaction processes and the role of biophysical and economic data in establishing true transdisciplinarity*

Each step of major KENGi activities is represented by a numbered box in the timeline of Figure 5. The idea to test the GWC management concept originated in 2004 with a case study presented at the World Water Week in Stockholm (Kauffman et al. 2004) and in an FAO e-Conference (Kauffman & Van Lynden 2004, Box 1 in Figure 5). A proof of concept was proposed to the International Fund for Agricultural Development (IFAD) and resulted in funding a GWC project in 2005 (Box 2). From the beginning, GWC was structured in three stages: (1) proof of concept – or *connected value proposition*; (2) validation and ground-testing – or *connected value creation*; and (3) mainstreaming into IFAD's learning and knowledge agenda, supporting IFAD decisions on its loan operations in Kenya, and beyond, by defining operational methodologies for GWC. This can be seen as *connected value capture*. Each stage was to be funded separately pending performance assessments.

In 2006, a start was made in Kenya with an exploratory study to verify the feasibility of the concept in a specific catchment, the Tana River basin. This exploratory study or proof of concept was financed by IFAD and Swiss Agency for Development and Cooperation (Boxes 3 and 4). Two-way arrows illustrate the intensive contacts resulting in this particular financial agreement. Baseline data were collected and a first workshop was held in Nairobi in 2006 (Box 5) to discuss intermediate results with 55 representatives from the farmer community, the private sector (Box 6) and the public sector (Box 7). One-way arrows illustrate that emphasis in this phase was still primarily on providing information to the various stakeholders. The GWC concept was unknown and experiences during the workshop clearly demonstrated a need for specific examples and hard data on possible benefits. In 2007, (Box 8) a proof of concept was presented based on six research reports (Dent & Kauffman 2007), presenting exploratory studies in four interacting domains needed to realize GWC: (1) soil and water management; (2) livelihoods; (3) institutions and regulations; and (4) financial mechanisms. These reports provided more clarity, particularly to potential funding agencies. As a result, the Kenya Government (Box 9) and IFAD (Box 10) approved the second phase of the GWC project in 2007, including a pilot design in the Upper Tana catchment. Research with more detail in comparison with the proof of concept, including field observations, was initiated for the four interacting domains which resulted in 10 reports, published in 2011, and results were discussed with all participants at different occasions while the work was in progress. Major delays were encountered in 2008 due to post-election violence in Kenya, but in 2009, two workshops were held (Box 11) with public and private partners (Boxes 12 and 13) and a national facilitator. Many

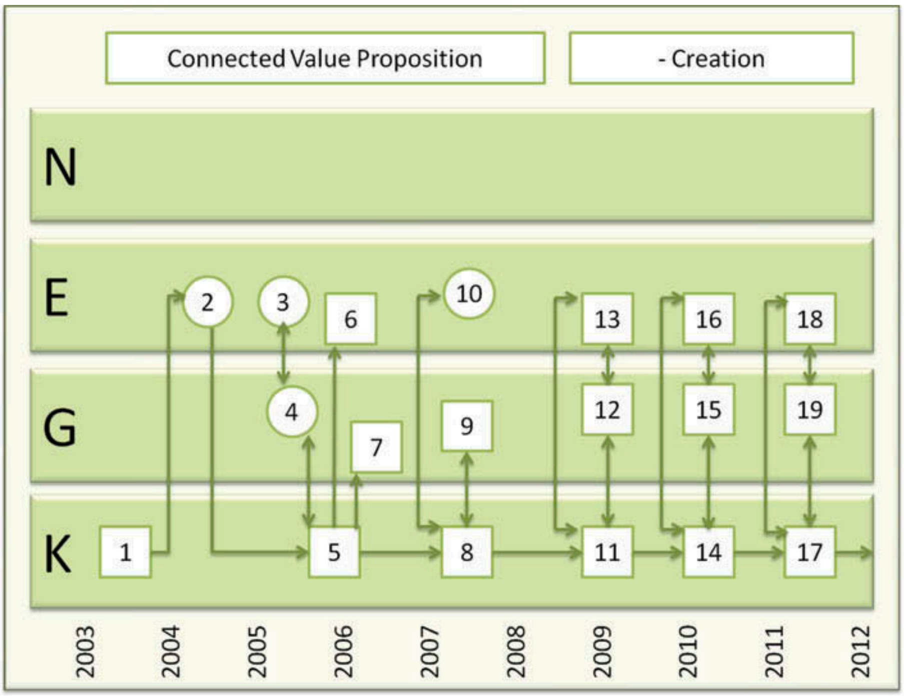

Figure 5. Timeline illustrating developments after proposing and implementing a GWC approach in the Tana River basin, Kenya. K = knowledge community, G = governmental at different levels, E = enterprises and business, N = NGOs (for box numbers, see text).

questions were raised. Farmers wondered whether costs to be made, when investing in soil conservation, would be recovered. They were also not used to consider short- versus long-term benefits and wondered about possible payment schemes. For water and hydroelectricity companies, the idea that farmers could be convinced to improve soil management, thereby extending the life cycle of reservoirs, was new and they questioned farmers' motives as well as the underlying model calculations. Introduction of the ecosystems approach turned out to be quite valuable to demonstrate that soil erosion was not only an agricultural problem. In 2010, another follow-up workshop was held, again with all partners (Boxes 14, 15 and 16) to further discuss the research results, emphasize the quantitative data obtained, and to continue training and raise awareness. This resulted in increased understanding among all partners involved, which would most likely not have been reached without this succession of interactive workshops. The cost/benefit analyses, presented in Table 2, showed the potential advantages of the proposed procedures in a convincing manner while discussions about possible money transfer mechanisms resulted in a preference for intermediary-based transactions, where the Water Resources Management Authority (WRMA) could play a central role. Farmers from specific areas confirmed the simulated predictions of the current situation, which convinced them that exploratory results of future scenarios were realistic. Note that all the arrows beyond 2009 point in two directions, showing intensive interaction between the various partners and stakeholders. In the first half of 2011, practical institutional and financial studies were undertaken. These were carried out in collaboration with the stakeholders in the field, farmers, catchment managing entities and the most important downstream beneficiaries such as Kenya Electric Generating Company (KENGEN) and the Nairobi Water Company (NWC), to obtain up-to-date real cost and benefit figures for both upstream and downstream situations when SWC measures would be implemented. These were followed by interviews and discussions with financial institutions, such as the Equity Bank and the Water Services Trust Fund (WSTF), more than 20 community-based organizations, the Water Resources Management Authority (WRMA) and IFAD rural investments projects, to define a sustainable commercial investment package consisting of a mixture of grants and credits/loans. This package included both high short-term investments in establishing SWC measures and much lower but long-term investments to maintain these measures. In September 2011, finally, applying all results from the various discussions and studies, the comprehensive pilot design for the Upper Tana study was presented in two concluding workshops, one workshop in Nairobi at the policy level for private and public national and international parties (Box 17) and one in Nyeri for the field-level parties, including representatives of farmers, catchment managing entities and water user associations (box 18), with substantial input from governmental agencies (Box 19). During these workshops, reports were discussed, presenting the complete SWAT and WEAP analyses as well as the socio-economic field interviews with farmers and the institutional and financial surveys analysing the institutions and regulations supporting the land users to improve their soil and water management practices by financial, legal and institutional support. The farmers were particularly interested in the commercial investment model that was presented, showing short- and long-term investments covering both farm production and resource protection goals.

All major national stakeholders, including those from the private sector and from regulatory bodies, as well as international GWC partners and the major funding agency IFAD, participated in these 2011 meetings. These project meetings were successful in establishing *connected value creation,* while activities before 2010 are considered to be part of the *connected value proposition* phase (Figure 5). Time was included in these workshops to initiate impromptu meetings between upstream and downstream private and public stakeholders such as WRMA, KENGEN, WSTF, NWC and IFAD to define follow-up actions for implementation projects in future, which are considered part of the *connected value capture* phase. At the time of this paper preparation, two SWC implementation projects, which take into account the GWC results, are being developed: one by the IFAD- supported Tana NRM project and one supported by the Nature Conservancy.

Sayer et al. (2013) defined 10 principles for a landscape approach to reconciling agricultural, conservation and other competing land uses. The GWC case study, reported here, has followed these principles, in fact, before the Sayer et al. (2013) paper was published: continued learning is a key element of *connected value development* and so is dealing with multiple scales, multifunctionality and multiple stakeholders (Sayer points 1, 3, 4 and 5). Common concern entry points, negotiated and transparent change logic and responsibilities (points 2, 6 and 7) were developed over time in this case study as part of the *connected value proposition* process. Monitoring, resilience and strengthening stakeholder capacity (points 8, 9 and 10) indeed need attention after *connected value capture* that has not been reached in this case study. The 10 principles of Sayers et al (2013) would be strengthened by adding the need for continued involvement of committed leaders and 'knowledge brokers' from the scientific community. This represents a significant break from the current practices, where commitments usually do not exceed periods of 4 years at most. Also, putting the principles in a time frame, allowing expressions of developments over time, would better represent reality, reflecting changing perspectives in a highly dynamic context. This is important to document the learning processes involved (e.g. Bouma, Van Altvorst, et al. 2011). The five steps of Hanson et al. (2012) were, also in retrospect, followed in this study. The Upper Tana Basin in Kenya was selected as step 1 because there ecosystem services were declining due to erosion. Three major ecosystem services were identified in step 2 relating to food production, water availability and energy production. Without any evidence to the contrary, continued erosion is most likely to occur and even to increase in the Upper Tana basin. As discussed, this trend (step3) would result in a decrease of the three major ecosystem services being distinguished. As governmental farmer subsidies to combat erosion are highly unlikely in the current political climate, attention is focused on water and electricity companies that would benefit from a reduction of upstream erosion, thus defining business risks and opportunities (step 4). However, to be convincing, a business case has to be based on hard data. That is why quantitative models, such as SWAT and WEAP, were applied in this study. Modelling exercises were backed up by field observations and socio-economic farm surveys. An implementation strategy (step 5) is being formulated and implementation has started as part of the *connected value creation* process, as described above. The five steps of Hanson et al. (2012) would be strengthened by more emphasis on interaction and learning processes among scientists, stakeholders and policy-makers during the entire process starting at initiation and ending at obtaining specific results in practice . Also, more emphasis on the need for producing hard data, for instance, by computer simulation, would be necessary, because this study demonstrated that only hard data is convincing. This creates a special responsibility for scientists to document model reliability and accuracy.

4. Conclusions

(1) The SWAT model was successfully used to explore the effects of 11 soil conservation measures on three major ecosystem services, relating to food production, water availability and energy production provided by the Upper Tana basin in Kenya. Framing effects of soil erosion in terms of diminishing ecosystem services appears to be a more effective form of communication, as compared with expressions in terms of soil losses as such. Framing is strengthened substantially by quantitative modelling of the ecosystem services.

(2) The GWC concept was supported successfully by calculating benefits versus costs with the WEAP model for each of the 11 soil conservation measures. Future investment funds for upstream farmers, intended to introduce proper soil conservation measures benefiting downstream water users, are more likely to materialize considering the favourable benefit/cost data presented. The calculated benefits versus costs were supported by field surveys including detailed interviews with farmers.

(3) Long-term continued interaction of soil and water researchers with all stakeholders involved was crucial for laying the foundations for the GWC approach. This was very time-consuming but worthwhile, as it resulted in *connected value creation* in 2011, implying that even though interests, values, goals and knowledge levels of the various stakeholders were initially quite different, they agreed, in the end, to join forces to achieve a GWC system in practice. *Creation* was preceded by an intensive *connected value proposition* activity, lasting 6 years. Many projects don’t allow that much time to be spent on research but not allowing this type of investment is likely to result in short, isolated technical studies with no follow-up.

(4) The next phase of *connected value capture* still requires much work as the proposed financial, institutional and political advice has to be put into practice. Continued involvement of soil and water scientists is needed as the *capture* process unfolds, to make sure that GWC principles are adhered to, realizing that only *connected value capture* will, in the end, convince stakeholders of the relevance of soil and water research.

References

Banwart S. 2011. Save our soils. Nature. 474:151–152. doi:10.1038/474151a

Batjes NH. 2012. Projected changes in soil organic carbon stocks upon adoption of recommended soil and water conservation practices in the Upper Tana River catchment, Kenya. Land Degrad Dev. doi:10.1002/ldr.2141

Bouma J. 2010. Implications of the knowledge paradox for soil science. Adv Agron. 106:143–171. doi:10.1016/S0065-2113(10)06004-9

Bouma J, Droogers P, Sonneveld MPW, Ritsema CJ, Hunink JE, Immerzeel WW, Kauffman S. 2011. Hydropedological insights when considering catchment classification. Hydrol Earth Syst Sci. 15:1909–1919. doi:10.5194/hess-15-1909-2011

Bouma J, Van Altvorst AC, Eweg R, Smeets PJAM, Van Latesteijn HC. 2011. The role of knowledge when studying innovation and the associated wicked sustainability problems in agriculture. Adv Agron. 113:285–314.

Bunders JFG, Broerse JEW, Keil F, Pohl C, Scholz RW, Zweekhorst MBM. 2010. How can transdisciplinary research contribute to knowledge democracy? In: ‘t Veld RJ, editor. Knowledge democracy. Consequences for science, politics and media. Dordrecht: Springer-Verlag.

Daniel TC, Muhar A, Arnberger A, Aznar O, Boyd JW, Chan KM, Costanza R, Elmqvist T, Flint CG, Gobster PH, et al. 2012. Contributions of cultural services to the ecosystem services agenda. Proc Nat Acad Sci. 109:8812–8819. doi:10.1073/pnas.1114773109

De Fries RS, Foley JA, Asner GP. 2004. Land-use choices: balancing human needs and ecosystem function. Front Ecol Environ. 2:249–257. doi:10.1890/1540-9295(2004)002[0249:LCBHNA]2.0.CO;2

Dent DL, Kauffman J. 2007. The spark has jumped the gap: green water credits proof-of-concept. Green Water Credits Report 7. Wageningen: ISRIC-World Soil Information.

Dijkshoorn JA, Macharia PN, Huting JRM, Maingi PM, Njoroge CRK. 2010. Soil and terrain database for the Upper Tana River, Kenya. Green Water Credits report 11. Wageningen: ISRIC-world soil information.

Droogers P, Hunink J, Kauffman S, Van Lynden G. 2011. Costs and benefits of land management options in the Upper Tana, Kenya: using the water evaluation and planning system – WEAP. Green Water Credits report 14. Wageningen: ISRIC – World soil information.

Droogers P, Van Loon A, Immerzeel W. 2008. Quantifying the impact of model inaccuracy in climate change impact assessment studies using an agro-hydrological model. Hydr Earth Syst Sci. 12:1–10.
Egoh BN, O'Farrell PJ, Charef A, Josephine Gurney L, Koellner T, Nibam Abi H, Egoh M, Willemen L. 2012. An African account of ecosystem service provision: use, threats and policy options for sustainable livelihoods. Ecosyst Serv. 2:71–81. doi:10.1016/j.ecoser.2012.09.004
Falkenmark M. 1995. Land-water linkages. FAO land and water bulletin 15–16. Rome: FAO.
Food and Agricultural Organization. 1998. World reference base for soil resources. World soil resources reports, 84. Rome: FAO.
Food and Agricultural Organization. 2011. The state of the world's land and water resources for food and agriculture. Rome: FAO.
Gibbons M, Limoges C, Nowotny H, Schwartzman S, Scott P, Trow H 1994. The new production of knowledge: the dynamics of science and research in contemporary societies. London: Sage.
Githui F, Mutua F, Bauwens W. 2009. Estimating the impacts of land-cover change on runoff using the soil and water assessment tool (SWAT): case study of Nzoia catchment, Kenya / Estimation des impacts du changement d'occupation du sol sur l'écoulement à l'aide de SWAT: étude du cas du bassin de Nzoia, Kenya. Hydrol Sci J. 545:899–908. doi:10.1623/hysj.54.5.899
Grieg-Gran M, Noel S, Porras I. 2006. Lessons learned from environmental services. Green Water Credits report 2. Wageningen: ISRIC.
Guo ZW, Xiao XM, Li DM. 2000. An assessment of ecosystem services: water flow regulation and hydroelectric power production. Ecol Appl. 10:925–936. doi:10.1890/1051-0761(2000)010[0925:AAOESW]2.0.CO;2
Hanson C, Ranganathan J, Iceland C, Finisdore J. 2012. The corporate ecosystems services review: guidelines for identifying business risks and opportunities arising from ecosystem change. Washington (DC): World Resources Institute, WBCSD and Meridian Institute.
Hunink JE, Droogers P, Kauffman S, Mwaniki BM, Bouma J. 2012. Quantitative simulation tools to analyze up- and downstream interactions of soil and water conservation measures: Supporting policy making in the Green Water Credits program of Kenya. J Environ Manage. 111:187–194. doi:10.1016/j.jenvman.2012.07.022
Hunink JE, Immerzeel WW, Droogers P, Kauffman S, van Lynden G. 2011. Green and blue water resources for the Upper Tana Catchment, Kenya – soil-water management scenarios using the soil and water assessment tool. Green Water Credits report 10. Wageningen: ISRIC.
Hunink JE, Niadas IA, Antonaropoulos P, Droogers P, de Vente J. 2013. Targeting of intervention areas to reduce reservoir sedimentation in the Tana catchment (Kenya) using SWAT. Hydr Sci J. 58:1–15.
Hurni H, Giger M, Meyer K. 2006. Soils on the global agenda. Developing international mechanisms for sustainable land management. Prepared with the support of an international group of specialists of the IASUS Working Group of the International Union of Soil Sciences (IUSS). Eurosoil Conference; 2004 Sep 9; Freiburg. Bern (Switzerland): Center for Development and Environment.
JRC-EEA, 2010. The European environment-state and outlook (SOER) [Internet]. EC-Joint Research Center and European Environmental Agency; [cited 2013 Aug 29]. Available from: http://www.eea.europa.eu/soer
Kauffman JH, Mantel S, Dijkshoorn JA. 2004. Applications of regional soil and terrain, and soil management databases for green and blue water resource scenarios. In: Stockholm International Water Institute, editor. Abstracts of the World Water Week. Stockholm: Stockholm International Water Institute.
Kauffman JH, Van Lynden GWJ. 2004. Managing the water balance – how farmers determine green and blue water flows in the Save Basin in Zimbabwe. Electronic conference drought resistant soils: optimization of soil moisture for sustainable plant production, Nov 12–Dec 17; FAO, Rome.
Kremen C. 2005. Managing ecosystem services: what do we need to know about their ecology? Ecol Lett. 8:468–479. doi:10.1111/j.1461-0248.2005.00751.x
Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: current state and trends: findings of the conditions and trends working group. In: Hassan R, Scholes R, Ash N, editors. Millennium ecosystem Assessment. Washington (DC): Island Press.
Mantel S, van Engelen VWP. 1999. Assessment of the impact of water erosion on productivity of maize in Kenya: an integrated modelling approach. Land Degrad Dev. 10:577–592. doi:10.1002/(SICI)1099-145X(199911/12)10:6<577::AID-LDR365>3.0.CO;2-F
Neitsch SL, Arnold JG, Kiniry JR, Williams JR, King KW. 2002. Soil and water assessment tool (SWAT). Theoretical documentation, version 2000. College Station (TX): Taxes Water Resources Institute.
Ojea E. 2010. Classifying ecosystem services for economic evaluation: the case of forest water services. BIOECON Conference, Sep 27–28; Venice.
Pagiola S, Arcenas A, Platais G. 2005. Can payments for environmental services help reduce poverty? An exploration of the issues and the evidence to date from Latin America. World Dev. 33:237–253. doi:10.1016/j.worlddev.2004.07.011
Porras I, Grieg-Gran M, Neves N. 2008. All that glitters: a review of payments for watershed services in developing countries. London: The International Institute for Environment and Development.
Sayer J, Sunderland T, Ghazoul J, Pfund JL, Sheil D, Meijaard E, Venter M, Boedhihartono AG, Day M, Garcia C, et al. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation and other competing land uses. Proc Nat Acad Sci. 110:8349–8356. doi:10.1073/pnas.1210595110
Schomers S, Matzdorf B 2013. Payments for ecosystem services: a review and comparison of developing and industrialized countries. Ecosyst Services. doi:10.1016/j.ecoser.2013.01.002
Tengberg A, Fredholm S, Eliasson I, Knez I, Saltzman K, Wetterberg O. 2012. Cultural ecosystem services provided by landscapes: assessment of heritage values and identity. Ecosyst Services. 2:14–26. doi:10.1016/j.ecoser.2012.07.006
United Nations. 2010. Halving hunger: it can be done. Task force on hunger. London: Earthscan.
United Nations Environment Programme. 2007. Global environmental outlook GEO4-environment for development. Kenya (Nairobi): United Nations Environment Programme.
Van Latesteijn H, Andeweg K. 2011. The transforum model: transforming agro innovation toward sustainable development. Dordrecht: Springer-Verlag.
Wenger E, Mc Dermott R, Snyder WM. 2002. Cultivating communities of practice – a guide to managing knowledge. Boston (MA): Harvard Business School Press.
World Overview of Conservation Approaches and Technologies. 2007. Where the land is greener. In: Liniger H, Critchley W, editors. Case studies and analysis of soil and water conservation initiatives worldwide. WOCAT.
Wunder S. 2005. Payments for environmental services: some nuts and bolts. Occasional Paper 42. Jakarta (Indonesia): Center for Intern. Forestry Res. CIFOR.