Working Paper

Tradeoffs Among Ecosystem Services in the Lake Victoria Basin

Brent M. Swallow, Joseph Sang, Meshack Nyabenge, Daniel Bondotich, Thomas Yatich, Anantha Duraiappah, Makiko Yashiro

Eastern and Central Africa

World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

Tradeoffs Among Ecosystem Services in the Lake Victoria Basin

Brent M. Swallow, Joseph Sang, Meshack Nyabenge, Daniel Bondotich,
Thomas Yatich, Anantha Duraiappah, Makiko Yashiro

World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

Correct citation:. Swallow B, Sang J, Nyabenge M, Bondotich D, Yatich T, Duraiappah A, Yashiro M. 2008. Tradeoffs among ecosystem services in the Lake Victoria Basin. ICRAF Working Paper 69. Nairobi: World Agroforestry Centre. 39 Pgs

Titles in the Working Paper Series aim to disseminate interim results on agroforestry research and practices and stimulate feedback from the scientific community. Other publication series from the World Agroforestry Centre include: Agroforestry Perspectives, Technical Manuals and Occasional Papers.

Published by the World Agroforestry Centre
United Nations Avenue
PO Box 30677, GPO 00100
Nairobi, Kenya

Tel: +254(0)20 7224000, via USA +1 650 833 6645
Fax: +254(0)20 7224001, via USA +1 650 833 6646
Email: icraf@cgiar.org
Internet: www.worldagroforestry.org

Working Paper 69

About the authors

Brent Swallow	Principal Economist with the World Agroforestry Center (ICRAF) and currently Global Coordinator of the ASB Partnership for the Tropical Forest Margins. P.O. Box 30677, Nairobi, Kenya. Corresponding author e-mail: b.swallow@cgiar.org Phone: +254-20-7224000
Joseph Sang	Consultant in hydrology and GIS analysis World Agroforestry Centre (ICRAF), P.O. Box 30677, Nairobi, Kenya.
Meshack Nyabenge	Head of the GIS Unit World Agroforestry Centre (ICRAF), P.O. Box 30677, Nairobi, Kenya.
Daniel Bondotich	Agricultural engineer and soil conservation officer Kenya Ministry of Agriculture, P.O. Box 138, Kiritiri, Kenya. Contributed to this project while a consultant to the World Agroforestry Centre.
Thomas Yatich	Research Officer in Environmental Policy. World Agroforestry Centre (ICRAF), P.O. Box 30677, Nairobi, Kenya
Anantha Duraippah	Chief of the Ecosystem Services Economics Unit Division of Environmental Policy Implementation (DEPI), United Nations Environment Programme (UNEP).
Makiko Yashiro	Programme Officer, Division of Environmental Policy Implementation, United Nations Environment Program (UNEP), Nairobi Kenya

Abstract

Lake Victoria is a crucial ecosystem for over 25 million people in Kenya, Uganda, Tanzania, Rwanda and Burundi who live in the basin, and for the greater Nile river system downstream of the lake. Ecosystem management in the Lake Victoria basin has been highly extractive for most of the last 60 years, with the 1990s marking a period of decline in food production, economic contraction, rising poverty, increased burden of human disease, and increased floods. Lake Victoria itself is becoming eutrophic, with related problems of species extinctions and invasive species.

Concepts and approaches from the Millennium Ecosystem Assessment were applied in a study of ecosystem service tradeoffs in two of the river basins that flow into Lake Victoria from Kenya (Yala and Nyando). Hydrologic units are the main geographic unit for analysis, with flows of water and sediment acting as the main integrator of provisioning and regulating services. The SWAT hydrologic model is calibrated to baseline data for the watershed and used to simulate water availability, water use and runoff, and sediment movement across the watershed. Provisioning services are evaluated through a spatially-disaggregated analysis of agricultural production, yield and area that combines spatial data from aerial photographs with division-level price and yield estimates.

The results illustrate large year-to-year variation in food supply, non-food agricultural production, sediment yield and flood risk in the two basins. The results indicate both synergies and tradeoffs between provisioning and regulating services, with results from the Yala basin much more consistent than for the Nyando. Simulation results show that conservation agriculture has potential to enhance regulating services in synergy with provisioning services. Policies conducive to smallholder agriculture and land conservation can generate greater synergies.

Keywords

ecosystem services, Kenya, hydrologic modelling, valuation, conservation agriculture, Lake Victoria

Acknowledgements

The study reported in this paper was conducted under a project entitled: "Sustaining the Values of Ecosystem Services in the Lake Victoria Basin." The project was supported by the United Nations Environment Programme and the World Agroforestry Centre. Financial support was also provided by the European Union. The contents of this publication are the sole responsibility of the authors and can in no way be taken to reflect the views of the funding agencies.

The authors acknowledge several Kenya government agencies that provided data used in the study, especially the Department of Resource Surveys and Remote Sensing that did the analysis of aerial photographs used in the study. The study benefited from useful comments provided by the participants of the project workshop held in Kisumu in June 2007 and from all those attending the presentation at the International Conference on Food Security and Environmental Change held at Oxford University in April 2008.

Contents

1. Introduction

The Millennium Ecosystem Assessment (MA) gave the world several important insights into the inter-dependence of human society and the natural environment. Besides synthesizing expert assessments of the state of human influence on the environment, it also provided new ways of conceptualizing human – environment interactions. By integrating the concepts of ecosystem services and human well-being, the MA helped to clarify the multiple ways that people depend on the environment. Sub-global assessments, such as the one conducted for Southern Africa, showed how the MA concepts can be applied in empirical studies at multiple spatial scales (Van Jaarsveld et al. 2005). A simple result of the assessment is that there are both tradeoffs and synergies between provisioning, regulating, support and cultural ecosystem services.

This paper reports the results of a study of ecosystem services tradeoffs in two river basins of the Lake Victoria basin in East Africa. The river basins are the Nyando and Yala, both of which drain into Lake Victoria from the Kenyan portion of the lake basin. Although the two basins are of similar size, and have their headwaters in the same range of forested hills, they have distinct biophysical and socio-economic characteristics. The outputs from this study have multiple uses, including decentralized planning and policy implementation in the agricultural, environment and water sectors. The outputs are also contributing to an evaluation of the potential for using payments for environmental services to harmonize the goals of the multi-lateral environmental agreements and the Millennium Development Goals.

1.1 Lake Victoria basin

Lake Victoria, the world's second largest freshwater lake, is located in the upper reaches of Africa's Nile River system. Lake Victoria has a surface area of about 68,800 square kilometers and an adjoining land basin area of about 184,000 square kilometers. The lake basin is comprised of 11 river basins and a lake-edge area that drains directly into the lake. The largest river basin by far is the Kagera, which drains parts of Rwanda, Burundi, Tanzania and Uganda. The next largest basins are the Mara (Kenya and Tanzania), Gurumeti (Tanzania) and Nzoia (Kenya) (Awiti and Walsh 2000).

The basin ecosystem is crucial for the 25-30 million residents of Kenya, Uganda, Tanzania, Rwanda and Burundi who live in the lake basin and for the larger downstream Nile river system. Human population density in the basin is about 170 persons per square kilometer and the population is growing at a rate of about 3 percent per annum (UNEP 2006). The population mainly depends on extensive rainfed agriculture for domestic and commercial purposes. In addition, the Lake provides hydroelectricity power and inland water transport and supports many different industries such as trade, tourism, wildlife and fisheries. Poverty levels are high across the basin. The Inter-Academy Council (2004) has deemed the area one of Africa's most severe hunger hotspots.

Ecosystem management in the Lake Victoria basin has been highly extractive for most of the last 70 years, with the 1990s a period of declines in food production, economic contraction, rising poverty, increased burden of human disease (especially malaria and HIV / AIDS), and increased floods (see Verschuren et al. 2002; World Agroforestry Centre 2006; Swallow et al. 2007). Lake Victoria itself is becoming eutrophic as high levels of phosphorus and nitrogen have been deposited in the lake from the atmosphere, the surrounding catchment and from municipal centres (Scheren et al. 2000). Severe erosion in parts of the catchment has increased sediment deposition in waterways and in the lake. An invasion of water hyacinth was particularly severe in the late 1990s, affecting fisheries, municipal water supply systems, and transport.

1.2 Nyando and Yala river basins

The Nyando and Yala river basins drain directly into the east side of Lake Victoria, with both their headwaters in the Mau forest complex of Kenya. The locations of the Nyando and Yala river basins relative to Lake Victoria and the rest of Kenya are shown in Figure 1. The Yala basin stretches cuts across the Nyanza, Rift Valley and Western Provinces, while the Nyando straddles Nyanza and Rift Valley Provinces.

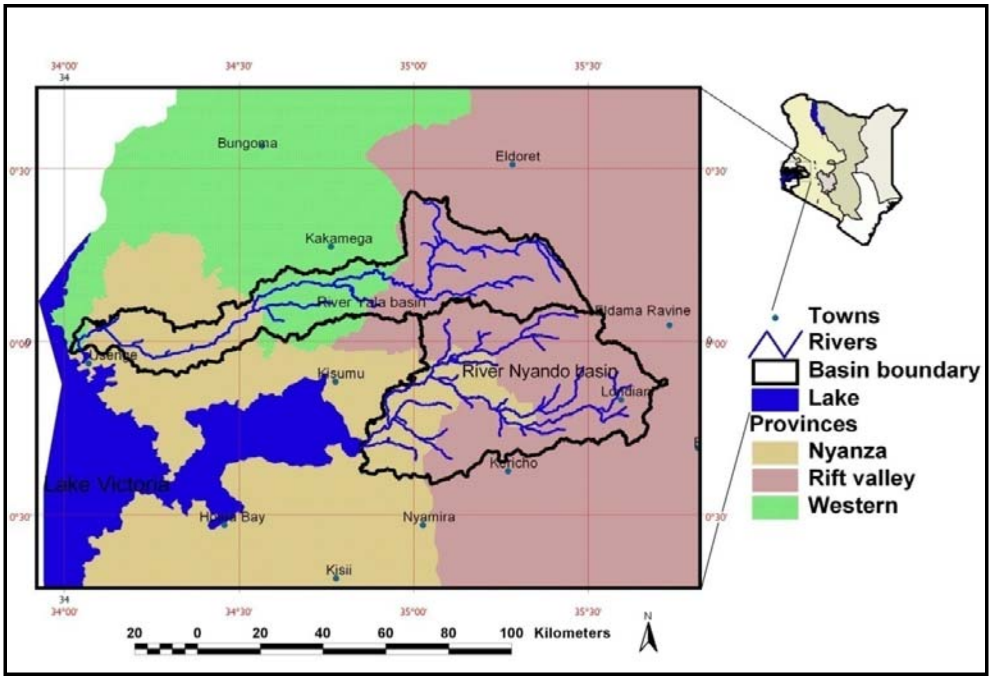

Figure 1. Map depicting geographic location of the Nyando and Yala river basins.

From a digital elevation model and GIS data on the stream network, we estimate that the Nyando river basin covers 3,587 km^2 while the Yala river basin covers 3,111 km^2. Both basins vary in altitude from about 3,000 meters above sea level at their headwaters to 1,184 meters above sea level where they drain into Lake Victoria. Climate in both basins varies with altitude, with increasing rainfall and decreasing temperatures with increasing elevation. Mean annual rainfall in the Nyando basin varies from about 1,000 mm near Lake Victoria to about 1,600 mm in the highlands. In the Yala basin, average annual rainfall is about 850 mm in the large flat area near Lake Victoria and up to 2,000 mm in the highlands.

The potential natural vegetation in the Nyando basin varies from acacia bushland in the lower basin, moist Combretum-Terminalia savanna in the mid-altitude area, and moist montane forest in the higher elevation areas. The potential natural vegetation in the Yala basin includes mixtures of broadleaf savanna and evergreen bushland in the lower basin, moist intermediate forest in the mid-altitude areas, and dry montane forest in the higher elevation areas (Kindt et al. 2005). At present, however, most land in the two basins has been converted into crop production, with small patches of bushland, forest and wetland remaining (World Resources Institute et al. 2007). The Nyando basin has a small area of intact natural forest in the headwaters area and a very small wetland at its outlet into Lake Victoria. The forest and wetland ecosystems of the Yala basin are considerably more intact. The Yala swamp is a large wetland area that separates the Yala river system from Lake Victoria. It is Kenya's largest freshwater wetland. As of the year 2000, the Yala swamp was degraded but still quite large (175 square kilometers), providing significant buffering of sediment and water flows between the river system and Lake Victoria. The Yala swamp is being degraded through a number of pressures, including expansion of farming, grazing, macrophyte harvesting, and catchment degradation (Thenya et al. 2006). Between 2005 and 2007, approximately half of the Yala swamp (69 square kilometers) was converted to commercial rice production (Kinaro 2008). Besides a small forest area in the Mau complex, the Yala basin also contains significant forest fragments in the mid-altitude area (Kakamega and South Nandi forests) (see Bleher et al. 2006).

The Nyando and Yala rivers contribute different loads of sediment and nutrients into Lake Victoria. Research by the World Agroforestry Centre shows that between 2000 and 2002, turbidity levels were 2-3 times higher in the Nyando than in the Yala (World Agroforestry Centre 2006, p. 13). While the Nyando basin occupies a very small percentage of the overall Lake Victoria basin, it makes a substantial contribution to sediment and nutrient loading of the lake.

Land degradation is widespread in both the Nyando and Yala basins, with severe gully erosion in the lower Nyando basin being the most visible sign of land degradation. A study of land degradation in the Nyando basin using the Cesium137 method estimated that 61.1 percent of the Nyando basin has experienced significant levels of erosion, with an average erosion loss of 43.5 tonnes per hectare (World Agroforestry Centre, 2006, pp. 14-15). Soil erosion and sedimentation have become increasingly severe over the last 60-100 years with increasing land conversion and farmland degradation. A radionuclide analysis of sediment cores extracted from the Winam Gulf at the mouth of the Nyando River shows that sedimentation rates have increased by three to four times over the last 100 years, with spikes in sedimentation occurring in association with years of particularly high rainfall (World Agroforestry Centre 2006, pp. 14-16). A study in the Yala basin by Awiti et al (2007) shows continual decline in land productivity and soil condition in agricultural lands around the Kakamega Forest over the 60 years since conversion from forest.

A GIS analysis of the 1999 population census data indicates that the Nyando basin had a population of about 656,000 people in 1999, for a population density of 183 persons per square kilometer, while the Yala basin had a population of about 1,079,000 people, for a population density of about 351 persons per square kilometre. Population density in the Yala varies from about 100 persons per square kilometre near Lake Victoria to 1200 persons per square kilometre in the mid-altitude areas of Vihiga District. Population density in the Nyando basin varies from about 50 persons per square kilometre in the mid-altitude area (sugar belt) to about 500 people per square kilometre in upper parts of the basin adjacent to Kericho town. Absolute poverty rates (also measured for 1999) are high and variable in both basins, with rates being highest in the lower Yala and in parts of the lower Nyando (over 65%) and lowest in upper parts of both basin (35-45%) (World Resources Institute et al. 2007, p. 17). The main agricultural activity is smallholder rainfed mixed farming. The Nyando basin also has a small amount of irrigated agriculture in the lower areas, large-scale commercial sugarcane in the mid-altitude areas, and both smallholder and large-scale tea production in the upper parts of the basin (World Agroforestry Centre 2006).

1.3 Ecosystem services and trade-off assessment

The conceptual framework for the Millennium Ecosystem Assessment (MA) posits that people are integral parts of ecosystems and that a dynamic relation exists between people and other components of ecosystems. Changes in human condition drive changes in ecosystems and subsequent changes in human well-being. At the same time, social, economic, and cultural factors external to ecosystems alter the human condition, and several natural forces also influence ecosystems. While the MA emphasizes the linkages between ecosystems and human well-being, it recognizes that human behaviour toward ecosystems is determined not just b y concerns about human well-being but also attitudes regarding the intrinsic value of species and ecosystems (Millennium Ecosystem Assessment 2005).

The global-level assessment of the MA reached four general conclusions. First, over the past 50 years humans have changed ecosystems more rapidly and extensively than in any comparable period in human history. Growing demands for food, fresh water, timber, fibre, and fuel have driven substantial and largely irreversible losses in the diversity of life on Earth. Second, changes in ecosystems have contributed to substantial net gains in human well-being and economic development, but at the cost of degradation of many ecosystem services, increased risks of non-reversible changes, and exacerbation of poverty for some groups of people. Third, degradation of ecosystem services could grow significantly worse during the first half of the 21st century and is a barrier to achieving the Millennium Development Goals (MDG). Finally, the challenge of reversing the degradation of ecosystems while meeting increasing demands for their services can be partially achieved under some scenarios, but would require significant changes in policies, institutions, and practices (Millennium Ecosystem Assessment 2005).

Tradeoffs between ecosystem services arise from management choices made by humans, which can change the type, magnitude and relative mix of services provided by the ecosystem. Tradeoffs occur when the provision of one ecosystem service is reduced as a consequence of increased use of another ecosystem service. In some cases, tradeoffs may be an explicit choice; in others, trade-offs arise without premeditation or even awareness that they are taking place. Rodríguez et al. (2006) propose that ecosystem service tradeoffs should be classified in three ways: across space, across time, and according to their reversibility.

Assessment of ecosystem tradeoffs can be done at different scales using different methods and tools. Separately, the tools of ecology and economics have advanced much faster than the integrated methods necessary for real descriptive and predictive power. Further development of combined models of ecosystems and economic activities is needed to better inform decision-making and environmental policy development (Boyd and Banzhaf 2005). This paper integrates outputs from geographic, hydrological and economic analysis to assess temporal and spatial tradeoffs in the Nyando and Yala basins.

2. Methods and data

The empirical approach adopted in this study roughly follows the approach taken in the Southern African Sub-Global Assessment (SAfMA) (see Van Jaarsveld et al. 2005). The current assessment focuses on two core groups of ecosystem services: provisioning services generated through agricultural production, and regulating and support services mediated by water. Further research in the two basins will put greater emphasis on cultural services mediated by biodiversity and human health as an indicator of human well-being.

This study was conducted at three spatial scales, considering both hydrologic response units and administrative units. The smallest spatial unit is the sub-basin that is defined by the natural hydrologic boundary based on a land unit with a single water one outlet. The intermediate unit is the division, the smallest administrative area at which agricultural production is reported in Kenya. The larger spatial unit is the river basin. One of the challenges for the study was the re-definition of production data into the boundaries of hydrologic units. Data from aerial photographs were used to spread agricultural production across the landscape and these data were aggregated to both the division and sub-basin levels.

2.1 Hydrologic modelling of regulating and support services

Soil erosion rates were simulated using a GIS-based version of the Soil and Water Assessment Tool (SWAT). SWAT is a physically-based, continuous-time and distributed-parameter model designed to simulate the impact of management practices on water, sediment and agricultural chemical yield in large and complex watersheds (Jha et al. 2004, Spruill et al. 2000). The model was used to simulate temporal and spatial water relations in the two river basins. Sediment yield and water yield were the main indicators of hydrologic impact. Higher levels of sediment yield are an indicator of declines in regulatory services (esp. flood mitigation) and supporting services (eg. soil formation, primary productivity). Higher levels of water yield are an indicator of higher levels of provisioning services (freshwater), but an indicator of lower levels of regulatory services (esp. water flow regulation). The SWAT model has previously been used to study the effects of proposed water reservoirs on flood risk in the lower Nyando basin (Sang et al. 2007), but had not been previously applied in the Yala basin.

SWAT requires information on land use, topography, soils and climate. Topographic data were obtained from a Digital Elevation Model (DEM) generated from digitized 50 meter-resolution topographical maps provided by Survey of Kenya. Land use maps for the two basins were generated from 2003 Aster satellite images (see Figures 2 and 3). Soil information was obtained from the Kenya Soil Survey (KSS), climate data from the Kenya Meteorological Department, and streamflow data from the Kenya Ministry of Water and Irrigation. A time series of data on climate and streamflow from the present back to the 1960s were collected where possible.

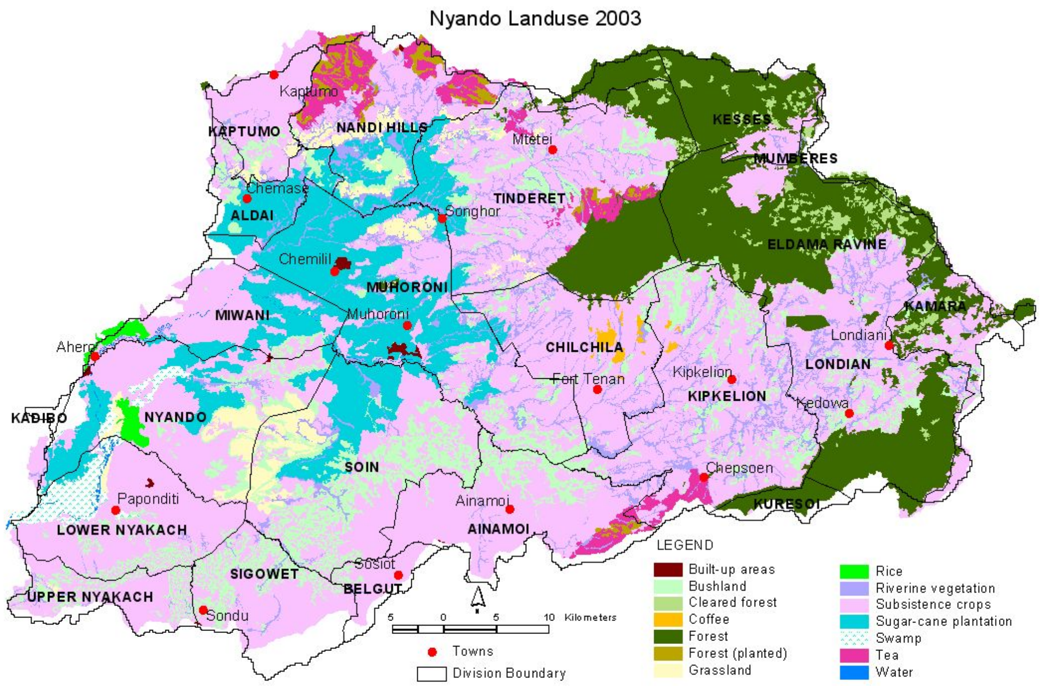

Figure 2. Landuse map of Nyando River Basin, 2003.

Source: World Agroforestry Centre GIS laboratory

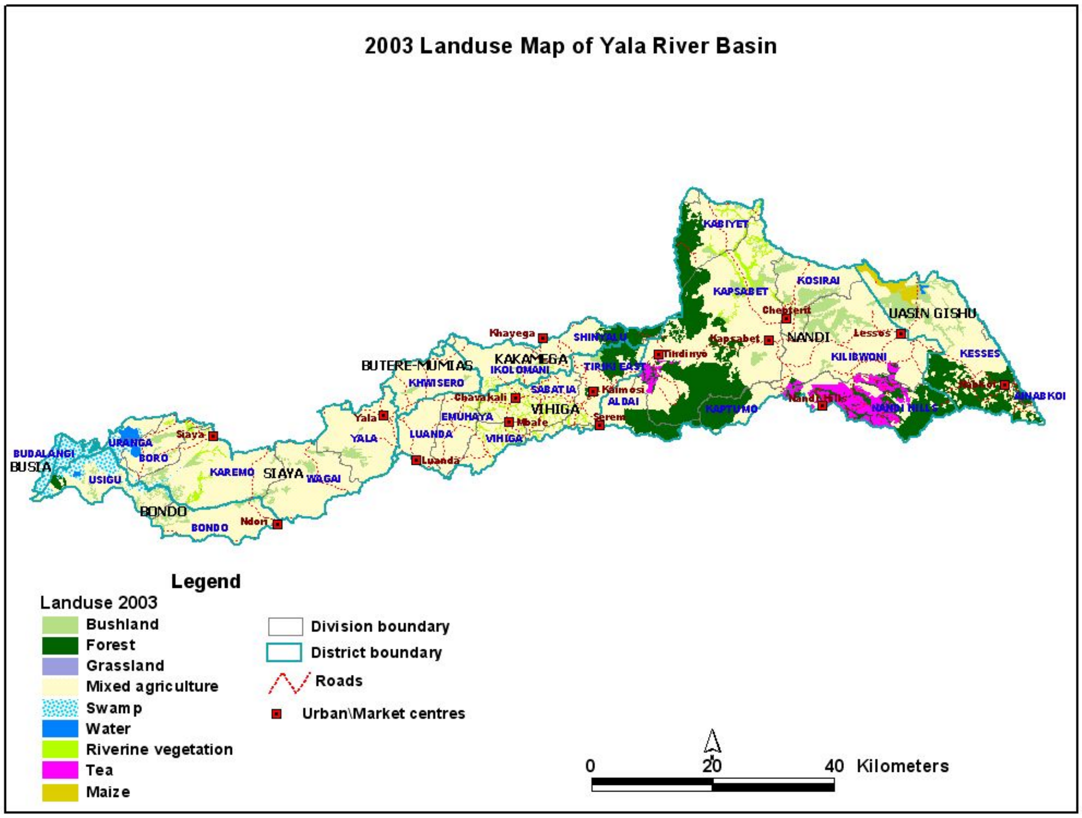

Figure 3. Land use map of Yala River Basin, 2003.

Source: World Agroforestry Centre GIS laboratory

The sediment yield estimates generated by SWAT are based on the universal soil loss equation which contains elements related to topography (LS -- calculated from the Digital Elevation Model), soil properties (K -- from the soils maps), rainfall (R -- from rainfall records), the crop factor (C -- from the land use map), and management practices (P). P factors were generated from a review of the available literature and reported in Sang et al. (2007). The following are the P factors that were used: agriculture (0.78), forests (0.28), tea (0.3), grazing land (0.4), sugarcane (0.5) and wetlands (0.40). Papers by Mati and Veihe (2001) and Cohen et al. (2005) suggest problems with applying the universal soil loss equation in Kenyan conditions. It was beyond the scope of this project to re-specify the SWAT model or to construct a new model.

One of the outputs of the SWAT model is a map of the hydrologic sub-basins – land units that have a single water outlet. On the basis of the Digital Elevation Model and streamflow data that were provided, the model identified 67 sub-basins in the Nyando and 54 sub-basins in the Yala. The average size of sub-basins was 53.5 square kilometres in the Nyando basin and 57.6 square kilometres in the Yala basin.

2.2 Quantification and valuation of agricultural production

Agricultural production data were collected for two time periods, 1999 and 2005. The year 1999 was chosen because it was the first year of significant research investment by the World Agroforestry Centre and extra development effort by the Ministry of Agriculture in the Nyando basin. The year 2005 was chosen because it was the most recent year of complete data at the time that the study was undertaken. Agricultural production data were only available for government administrative units, with divisions being the smallest administrative units at which data are recorded in Kenya. Data were collected on total production, area under production, yield, and prices paid by buyers to farmers. A questionnaire was used to collect data from government officers, tea and sugar cane factories, and agricultural purchasing centres, with the questionnaire administered in person by one of the authors with long experience working in the agricultural sector in the study area. Unpublished annual reports of division-level agricultural offices were a key source of information. Once compiled and displayed, the agricultural data were cross-checked through a workshop with about 40 experts and stakeholders in agricultural development in the region. For the most part, participants in the workshop verified some of the large changes in production that were noted, helping to improve interpretation of those results. A minority of the yield estimates emanating from the agricultural survey (for tea and sugarcane) proved to be unreliable, necessitating alternative estimation methods. The survey collected data only on the major agricultural crops in each basin. In the Nyando basin, this included maize, sorghum, sugar cane, tea, beans, and coffee. In the Yala basin, this included maize, sorghum, millet, sugar cane, tea, tomatoes, and cabbages. Unfortunately, comparative data on revenue from fruit trees, timber trees, or livestock were not available.

Kenya experienced substantial inflation in consumer prices during the 1999 to 2005 period. The annual rate of consumer price inflation was 5.7% in 1999, 10% in 2000, 5.7% in 2001, 2% in 2002, 9.8% in 2003 and 11.6% in 2005 (Export Promotion Council of Kenya). An aggregate inflation factor of 1.536 was calculated and used to adjust 1999 prices to 2005 terms.

2.3 Spatial data on agricultural production

Data on the spatial distribution and intensity of different enterprises were generated from sets of aerial photographs available for the years 1991, 1997 and 2006. These aerial photographs at a grid level of 5km by 2.5km were obtained and interpreted by the Kenya Department of Resource Surveys and Remote Sensing. Data from the photographs characterized the prevalence of a variety of land use types and included all of the crops included in the survey of agricultural production. These data were used for calculating the area of different agricultural systems in the divisions and hydrologic sub-basins. These data provided wall-to-wall coverage of the two basins, excluding small areas at the boundaries on the edges of the basin (especially the forested upper catchment areas).

The aerial photography data provided estimates of the percentage cover of the different agricultural systems for each of the 5km x 2.5km rectangular areas (scenes) covered by individual photos. GIS software (ArcView) was used to overlay the geographic coordinates of the scenes with the boundaries of the administrative divisions, with 4-10 scenes covering each division. For divisions on the boundaries of the river basins, only the part of the division located in the basin was included in the analysis. Data from the compiled scenes was then used to estimate the area of the different production systems in each division. The area estimates were multiplied by division-level yield estimates to generate production estimates, and production was multiplied by the division-level prices to generate estimates of revenue for each crop. Revenue for each crop was summed to produce an estimate of total revenue per division and per hectare per division.

To generate estimates of revenue per crop per sub-basin, GIS analysis was used to overlay the boundaries of the sub-basins (from the SWAT modelling) on the boundaries of the divisions. Sub-basins generally included parts of 2-4 divisions. The revenue associated with each crop per sub-basin was calculated as a weighted average of the revenue estimates for the relevant divisions, with the weights determined by the proportion of the division located in the sub-basin. One of the challenges this study faced was that agricultural production data and production intensity data were available for slightly different years. The aerial photography data for 1997 was therefore used to estimate production intensity in 1999, while the aerial photography data for 2006 was used to estimate production intensity in 2005.

2.4 Tradeoff Analyses

Temporal assessment of tradeoffs was generated three ways. First, an analysis of land use change was conducted on the basis of the interpreted aerial photography data from 1991, 1997 and 2006. Second, the disaggregated data on agricultural production for 1999 and 2005 were compared to identify overall and site-specific trends in yield, area and production. Third, the validated SWAT model was used to simulate annual sediment yields for the 20-year period between 1986 and 2006.

Spatial depiction of overall tradeoffs between hydrologic services and agricultural production for the year 2005 was generated through a spatial overlay of results on sediment yields and value of agricultural production at the sub-basin level. The sediment yield of each basin was expressed in terms of average sediment yield per hectare, the median sediment yield identified, and sub-basins characterized as having above-median or below-median sediment yield. Similarly, the agricultural production in each sub-basin was expressed in terms of value of production per hectare, and sub-basins characterized as having above median production or below median production. The results were then overlaid and sub-basins grouped into those with high sediment yield / high production, low sediment yield / high production, high sediment yield / low production, and low sediment yield / low production. The extent to which high production is associated with high sediment yield is taken to be an indicator of tradeoffs between provisioning and regulating services.

3. Results

3.1 Land use and land use change

Tables 1 and 2 present aggregate results of the land use analysis for 1991, 1997 and 2006 for the Nyando and Yala basins, respectively. The results for Nyando show large decreases in the area of natural vegetation from 1991 to 1997 and from 1997 to 2006. Overall, the area of natural vegetation decreased from 65 to 56 percent over the 15-year period, for an average decrease of 0.6% per year. The areas in both crop agriculture and tree production systems increased over these periods. While maize increased most in terms of area of increase (a net increase of 2.4% of the basin in maize), the percentage increases were greatest for rice, sorghum and vegetables. The total area covered by tree crops (4.64%) was constant between 1997 and 2006, with increases in area devoted to tea and fruit roughly matched by a decrease in the area of woodlots and hedges. Overall, the land use data for Nyando indicate tradeoffs between forests and maize, and between irrigated crops and intact wetlands. The results for crop agriculture in the Nyando basin show an increase in the already high percentage of agricultural land devoted to maize (88.8% in 1991 to 90.0% in 1997 to 92.9% in 2006), a considerable reduction in the area devoted to a range of minor cereal and cash crops (eg millet, pyrethrum, potatoes, cassava, napier grass, wheat), and an increase in higher-value crops requiring irrigation (rice, vegetables).

Table 2 indicates a considerably different land use and land use change situation in the Yala basin. The total area of natural vegetation was relatively constant over the 15-year period between 1991 and 2006, starting at 53.7% in 1991 and ending at 52.3% in 2006. During that time, the area of forest and bushland actually increased by about 3%, while the area of grazing, fallow and bare land decreased by about 4%. Total area in foodcrops increased from 1991 to 1997 and decreased from 1997 to 2006. The area of maize, which occupied about 90% of all crop land in all three periods, displayed a similar up-and-down trend. The data indicate that the areas devoted to all three crops (coffee, tea, fruit, woodlots) decreased marginally from 1991 to 1997. The main change in tree crops from 1997 to 2006 was the large increase in tea, from 2.9% to 5.3% of the area of the basin. The data for sugar cane indicate a surprisingly large increase from 1991 to 1997 and a similarly large decrease from 1997 to 2006. Overall, the data for Yala suggest relatively little net change in the area of natural vegetation, a large drop in the area in sugar cane production and small drop in the area in maize, but a large increase in the area of tea. The spatial tradeoffs seem to be among provisioning services rather than between provisioning and regulating services.

Table 1. Land use in the Nyando river basin, 1991, 1997 and 2006

	Land cover % in Nyando Basin		
Land use category	**1991**	**1997**	**2006**
Grazing, fallow, bare	37.9	34.0	30.9
Forest and bushland	24.63	24.44	24.38
Water bodies	0.36	0.27	0.19
Wetlands	1.93	0.90	0.40
Natural vegetation	**64.8**	**59.6**	**55.9**
Ploughed	1.38	0.64	0.28
Maize & maize mixes	12.69	12.94	15.39
Minor crops	0.18	0.32	0.08
Rice	0.00	0.37	0.45
Sorghum	0.01	0.01	0.05
Vegetables	0.02	0.09	0.31
Crop agriculture	**14.28**	**14.37**	**16.56**
Tea	0.75	1.91	2.89
Coffee	0.24	0.09	0.11
Fruit	0.11	0.07	0.11
Woodlots & hedges	1.57	2.61	1.53
Tree crops	**2.67**	**4.68**	**4.64**
Sugar cane	**7.76**	**10.75**	**8.99**
No data	**9.00**	**8.70**	**12.24**
Roads and structures	**1.51**	**1.84**	**1.68**
Total	**100.02**	**99.98**	**100.00**

Table 2. Land use in the Yala river basin, 1991, 1997, 2006

	Land cover % in Yala Basin		
Land use category	**1991**	**1997**	**2006**
Grazing, fallow, bare	36.3	36.6	32.2
Forest and bushland	13.67	14.38	16.07
Water bodies	1.30	0.33	0.51
Wetlands	2.42	2.46	3.53
Natural vegetation	**53.7**	**53.8**	**52.3**
Ploughed	0.85	1.35	0.78
Maize & maize mixes	18.08	19.22	16.38
Minor crops	0.64	1.37	0.68
Rice	0.00	0.00	0.00
Sorghum	0.00	0.02	0.00
Vegetables	0.02	0.04	0.08
Crop agriculture	**19.59**	**22.00**	**17.92**
Tea	3.51	2.93	5.31
Coffee	0.16	0.06	0.00
Fruit	0.87	0.73	0.82
Woodlots & hedges	4.37	4.04	3.75
Tree crops	**8.91**	**7.76**	**9.88**
Sugar cane	**0.12**	**6.87**	**0.40**
No data	**15.27**	**7.17**	**17.50**
Roads and structures	**2.38**	**2.27**	**1.98**
Total	**100.00**	**99.82**	**100.00**

3.2 Calibration and validation of the hydrologic model

Calibration of the water yield predictions of the SWAT model was done using streamflow data for the period 1982 to 1987, while calibration was done using streamflow data for the period 1988 to 1990. Data were available for three river gauging stations for the Nyando basin and one river gauging station for the Yala basin. The scattergram for the Yala basin calibration is shown in Figure 4. From the scattergram it is observed the simulated streamflow and observed streamflow correlate well with an R-Squared value of approximately 0.7. Calibrations for the Nyando basin (not shown) found similar levels of correlation. The SWAT model results can therefore be assumed to be a fair representation of water yield in the Nyando and Yala river basins.

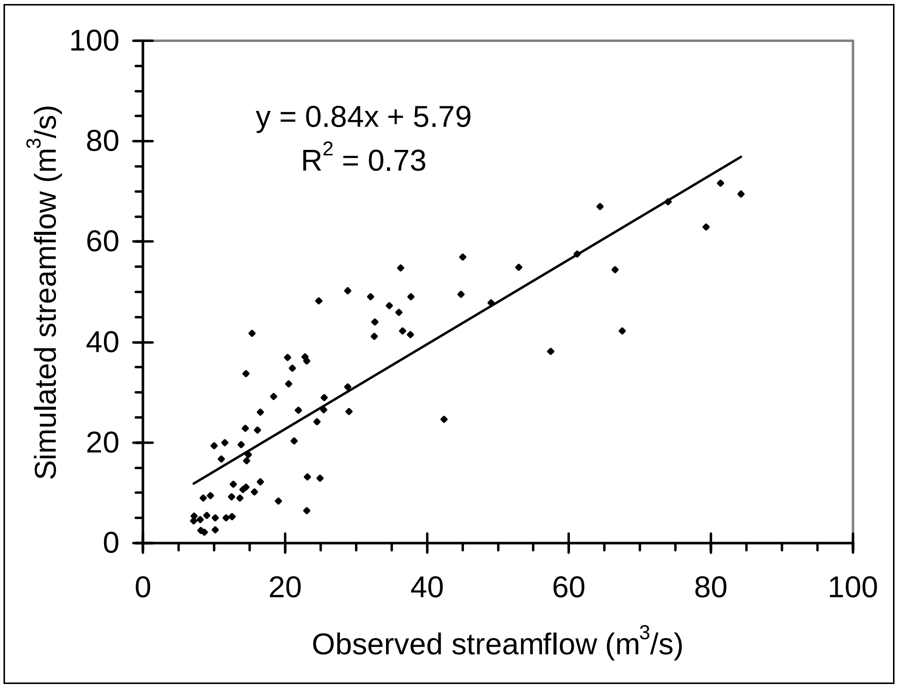

Figure 4. Calibration scattergram for streamflow in the River Yala basin.

Since there were no available records of sedimentation in Nyando or Yala river systems, the simulated sedimentation results were compared with estimates of sediment deposition at the mouth of the Nyando river presented in World Agroforestry Centre (2006). The Lead 210 (210Pd) chronology method was used to estimate annual sedimentation rates from sediment cores. Comparison of the two estimates of erosion showed a low correlation, suggesting low predictive power for the model at the whole basin level (Figure 5).

One explanation of the low predictive power of the sediment yield estimates generated by the SWAT model is that there are considerable time lags erosion and sediment movement along the river system into Lake Victoria. Another explanation is that the SWAT model does not address gully erosion while parts of the lower Nyando basin are characterized by severe gully erosion. The difference between the lower predictions of the SWAT model and the higher estimate from the Lead 210 chronology could be largely attributed to the amount of gully erosion.

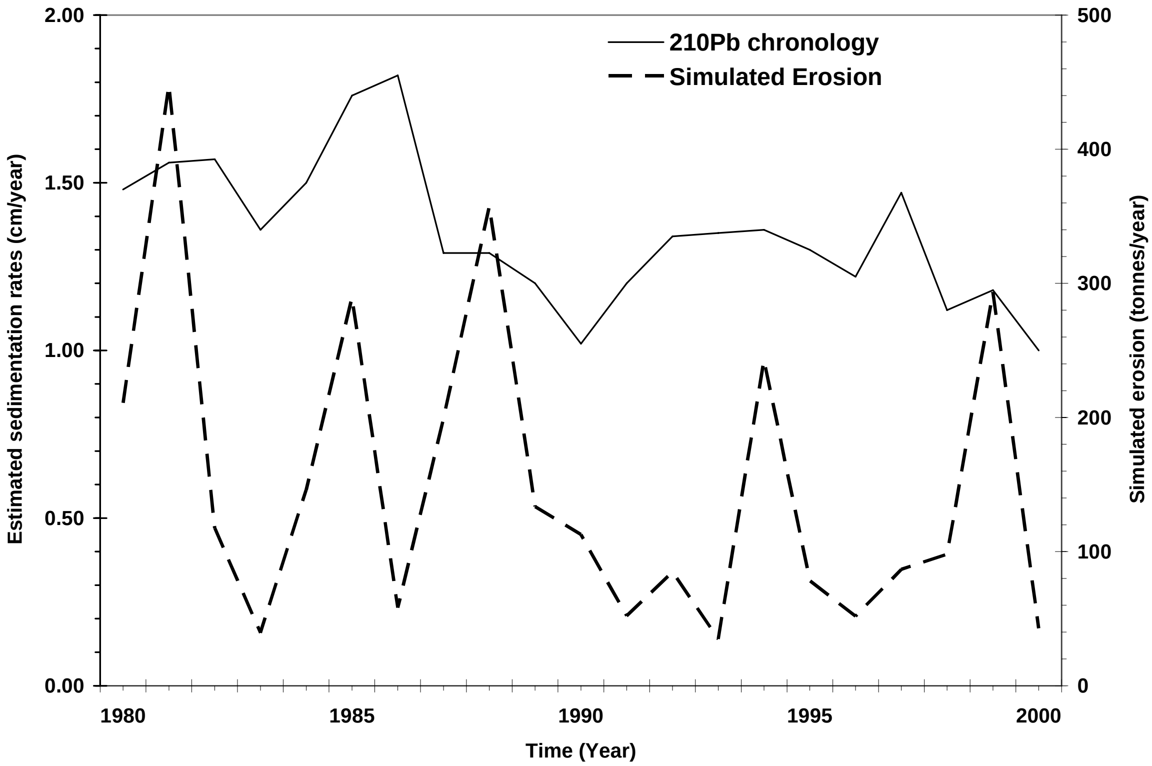

Figure 5. Comparison of estimated sedimentation rates and simulated erosion for the Nyando basin.

3.3 Spatial and temporal analysis of water and sediment yields

The spatial representation of the simulated mean water yield and erosion rates for the River Nyando and Yala are shown in Figures 6 and 7. Water yield is highest in the mid-altitude parts of the Yala basin, an adjacent area in the upper Nyando basin, and in the upper part of the Nyando on the southern side of the Nyando basin. Water yield is affected by the amount of rainfall, surface cover, topography and groundwater recharge. Sediment yield in the Nyando is predicted to be highest in the areas of highest water yield and in the mid-altitude areas that are characterized by high rainfall, annual crops, and sloping topography. The forested areas in the upper parts of both basins have lower rates of water yield and sediment yield.

The lower Yala and lower Nyando are predicted to be areas of lower water yield and lower sediment yield. It is likely, however that SWAT under-estimates sediment yield in those areas, particularly in the lower Nyando. The alluvial soils found in parts of the lower Nyando are known to be particularly prone to severe gully erosion. Again, recall that the SWAT does not consider gully erosion.

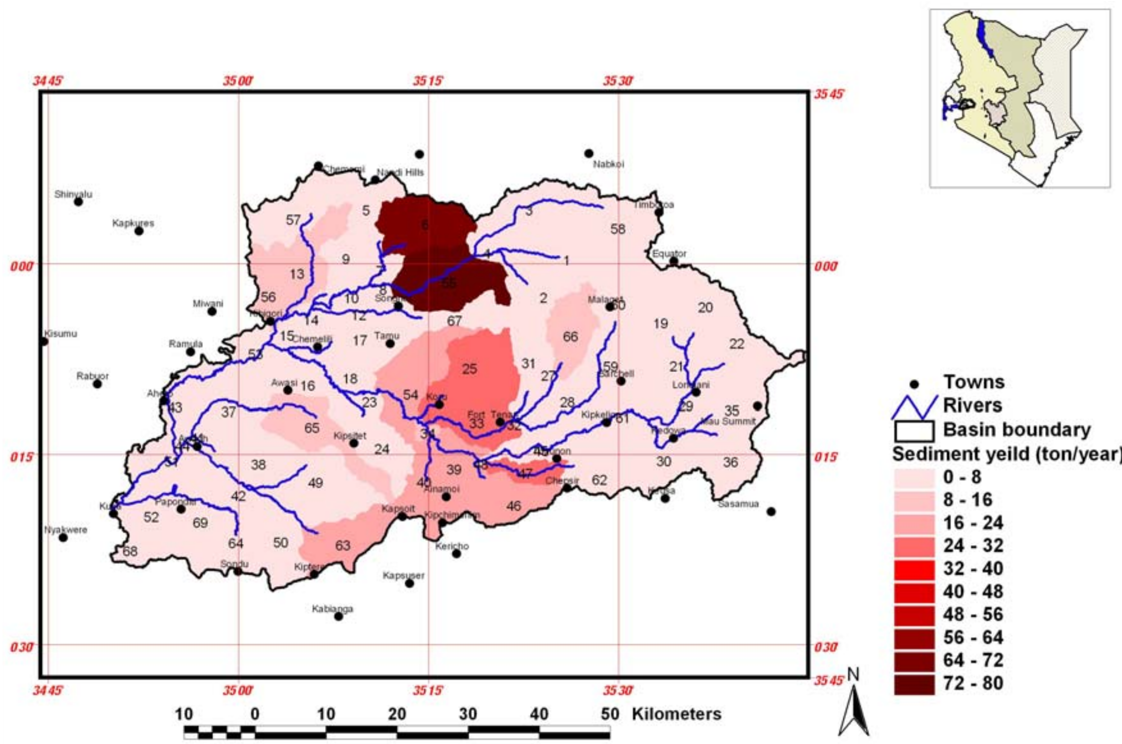

Figure 6a Predicted sediment yield by sub-basin the Nyando river basin.

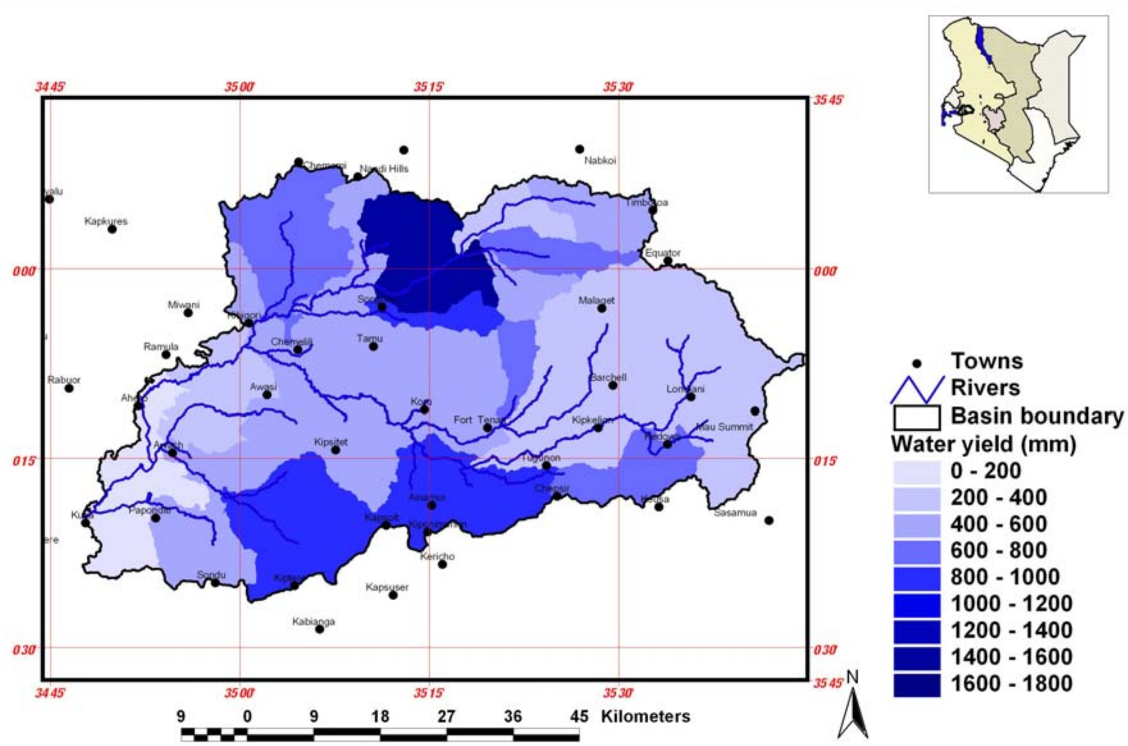

Figure 6b: Predicted water yield by sub-basin the Nyando river basin.

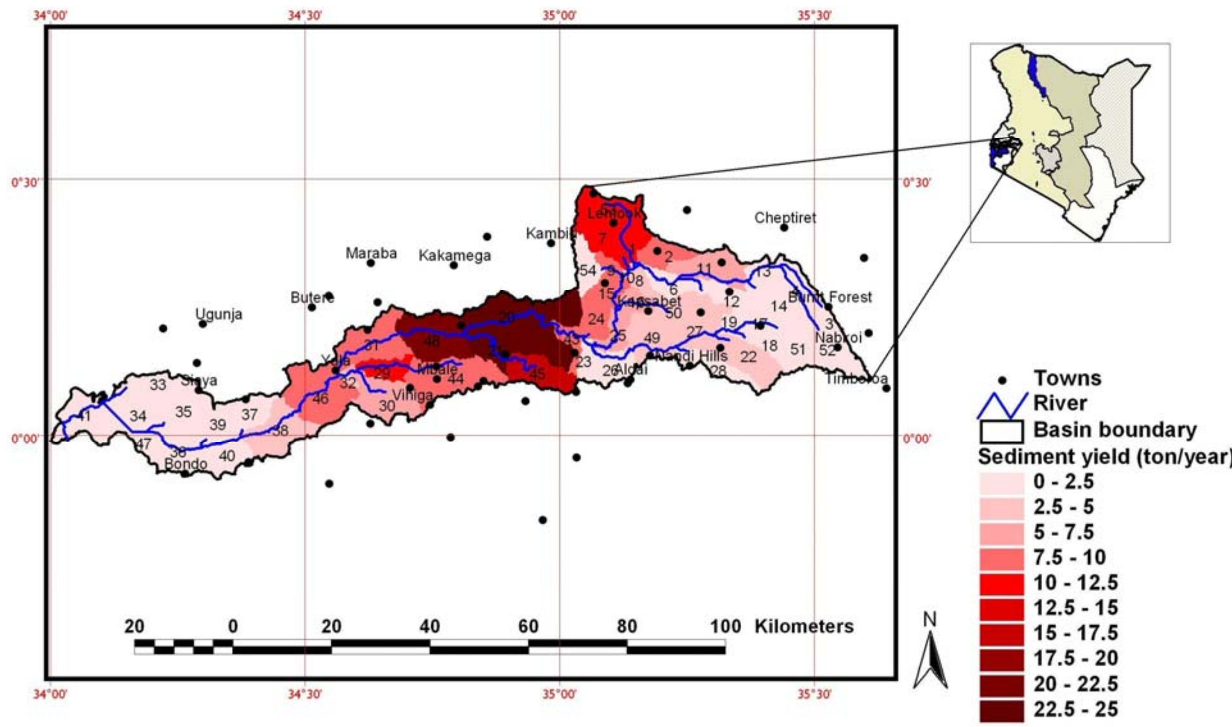

Figure 7a: Predicted sediment yield by sub-basin in the Yala river basin

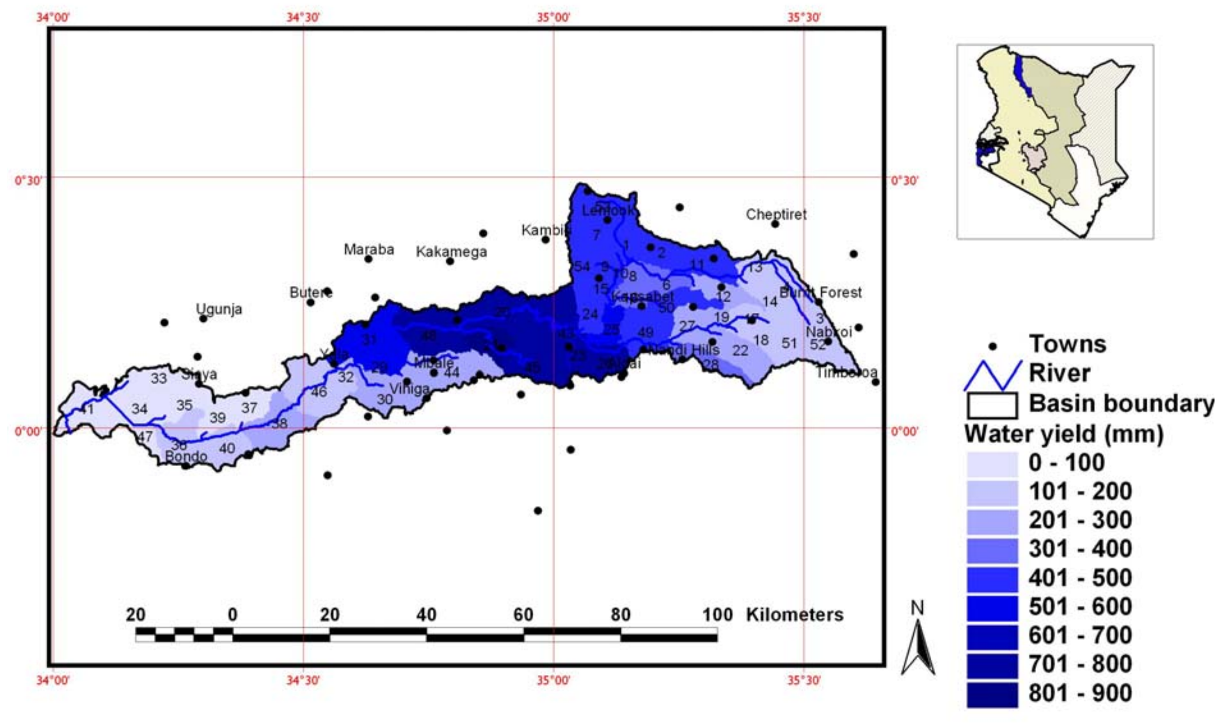

Figure 7b: Predicted water yield by sub-basin in the Yala river basin

The SWAT model was also used to evaluate changes in sediment yield over time for the Yala and Nyando basins. Figures 8a and 8b illustrate the model predictions of annual sediment yield for the Nyando and Yala basins, respectively, for each year from 1986 to 2004. Year-to-year differences in sediment yield result from the different climatic conditions that prevailed. The results suggest annual erosion losses of between 1-3 million tonnes per year in the Nyando, and between 2-3 million tonnes per year in the Yala. If climate change results in greater variation in inter-annual and intra-annual rainfall, we should expect greater variation in erosion losses and sedimentation rates.

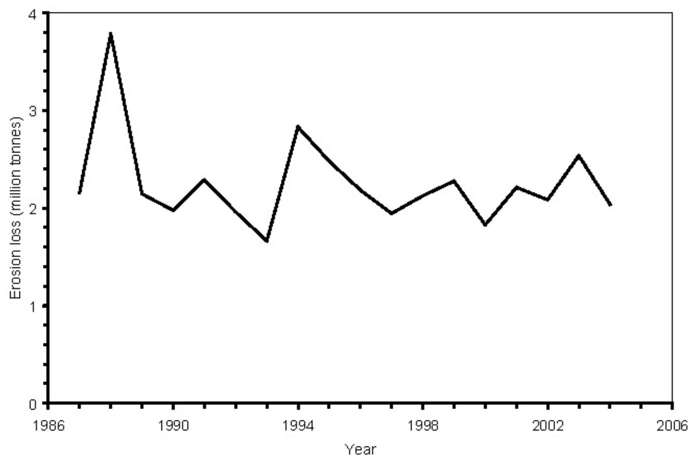

Figure 8a: Predicted sediment yield for the Nyando basin by year, 1987 to 2005.

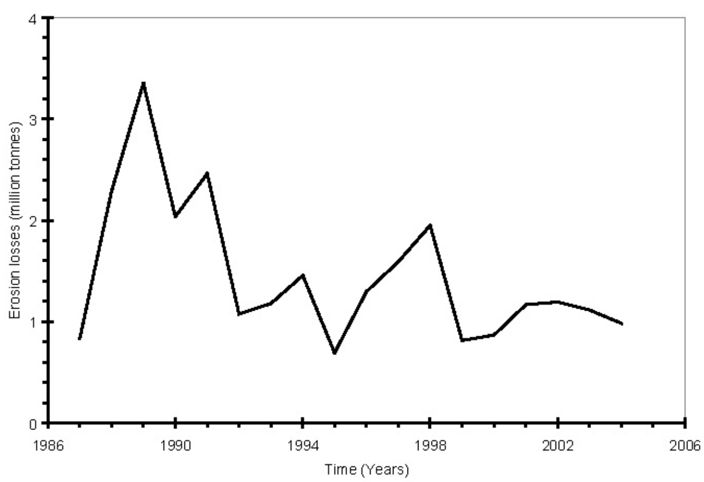

Figure 8b: Predicted sediment yield for the Yala basin by year, 1987 to 2005.

3.4 Trends and tradeoffs in agricultural production

As explained above, this study uses the monetary value of agricultural production as an indicator of provisioning ecosystem services. As discussed in the methods and data section of the paper, this study produced estimates of the quantities and values of major agricultural crops in each administrative division, and in each sub-basin for the years 1999 and 2005. Values are expressed in nominal terms for 1999 and 2005, and in 2005 real terms. Those detailed data are available upon request. For the current purposes, we report two key results. The first result is the geographic distribution of the value of agricultural production in the two basins in 1999 and 2005, aggregated at the sub-basin level and whole basin levels and expressed in real 2005 Kenya shillings. The second result is the change in the aggregate value of agricultural production between 1999 and 2005, again aggregated at the sub-basin and basin levels.

Results presented for the Nyando basin for 1999 in Figure 9a show remarkable differences in the value of production across the basin, with the value of production around Ksh 45-50,000 per hectare in the mid-to-upper altitude areas around Kericho town in the southern part of the basin (primarily Anamoi Division) and in the mid-altitude areas in the area around Songhor in northern part of the basin (primarily Tinderet division). In contrast, value of production was less than Ksh 5,000 in the lowest parts of the Nyando basin and Ksh 5,000-15,000 per hectare in the mid-altitude sugarcane belt. Both of the areas with highest production include a mixture of tea and mixed smallholder agriculture.

The results for Nyando for 2005 in Figure 9b show a similar spatial pattern of production to that of 1999. The results indicate some reduction in revenue in the areas that had highest revenues in 1999, that is, the tea / mixed agriculture areas near Kericho (Anamoi Division) and Songhor (Tinderet Division). Some of the mid-altitude areas in the sugarcane belt and around Koru and Kipkelion had somewhat higher value of production in 2005 than in 1999. The results for 2005 also suggest that the value of agricultural production was low in 2005 (less than Ksh 10,000 per hectare) in all of the Awach basin in the lower southern part of the basin (Lower Nyakach and Sigowet Divisions).

A more nuanced perspective on changes in the value of agricultural production is provided by Figure 9c. That figure displays the ratio of value of agricultural production in 2005 to value of agricultural production in 1999 (measured in real 2005 terms). The results show a marked decline in Sigowet division in the upper Awach area, and smaller declines (ratios less than 1) across much of the mid-altitude areas and upland areas that had the highest value of production in both 1999 and 2005. The results show increases in production (ratios between 1 and 1.6) in the lower Nyando area (although value of agricultural production is still low in absolute terms), in part of the sugarcane belt area, and especially in the highest altitude areas around Kipkelion, Londiani and Malaget.

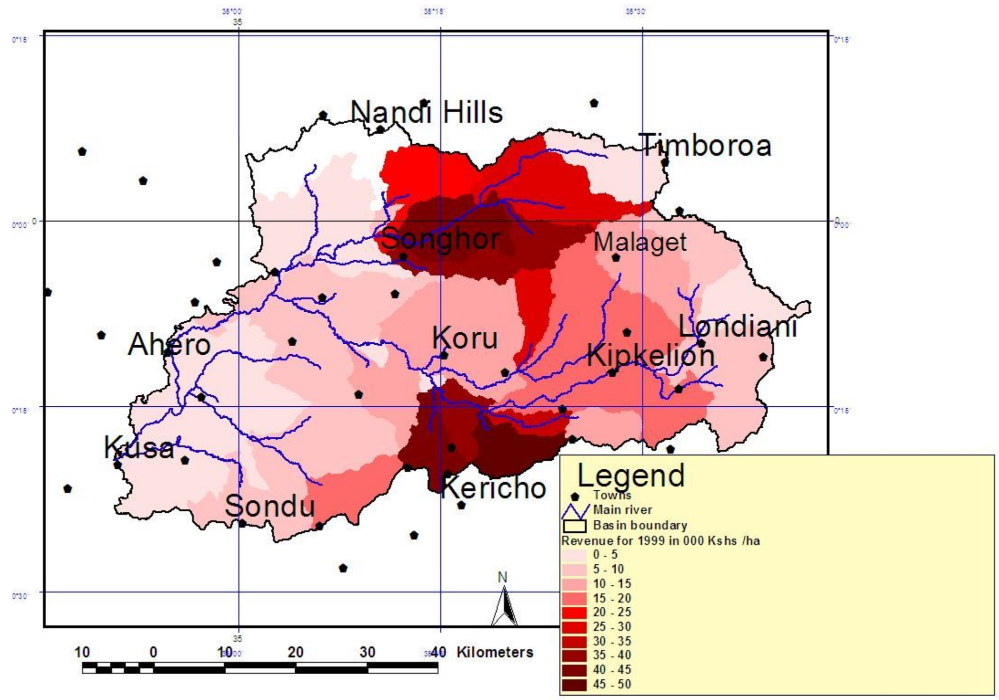

Figure 9a: Value of agricultural production per hectare per sub-basin in the Nyando basin, 1999 (expressed in thousands of Kenya shillings in 2005 terms).

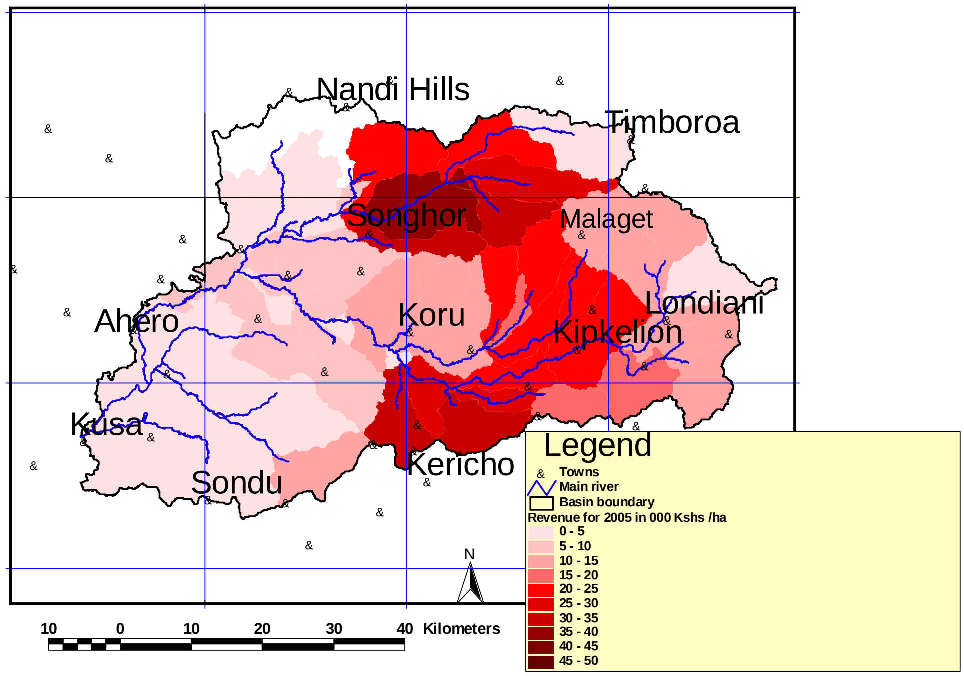

Figure 9b. Value of agricultural production per hectare per sub-basin in the Nyando basin, 2005 (expressed in thousands of Kenya shillings in 2005 terms).

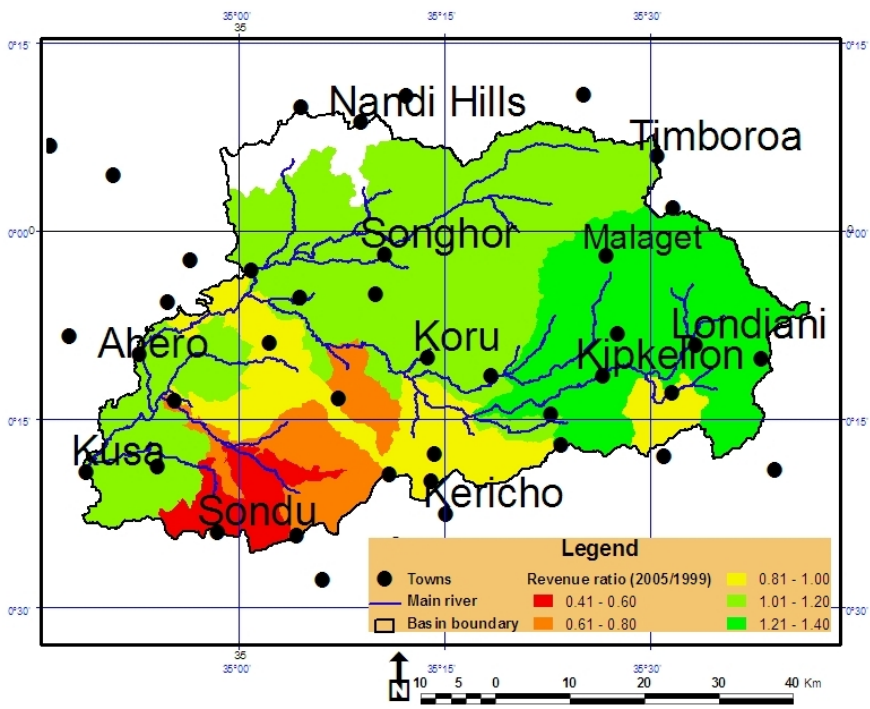

Figure 9c. Ratio of value of agricultural production per hectare in 2005 / 1999 per sub-basin in the Nyando basin, 2005 (ratios less than one indicate reductions, ratios greater than one indicate increases).

Results on the value of agricultural production for the Yala basin are presented in Figures 10a, 10b and 10c. The results presented in Figures 10a and 10b show that the value of agricultural production increases with altitude from the lake shore area to the highest altitude parts of the basin near the town of Kapsabet. Results presented in Figures 10c on the ratio of value of production in 2005 to 1999 indicate that the value of production generally declined between 1999 and 2005 in the lower and mid-altitude parts of the basin, while it increased in the highest parts of the basin. The areas around Kapsabet and Kasirai had increases in production per hectare of up to 60% in 2005 real terms.

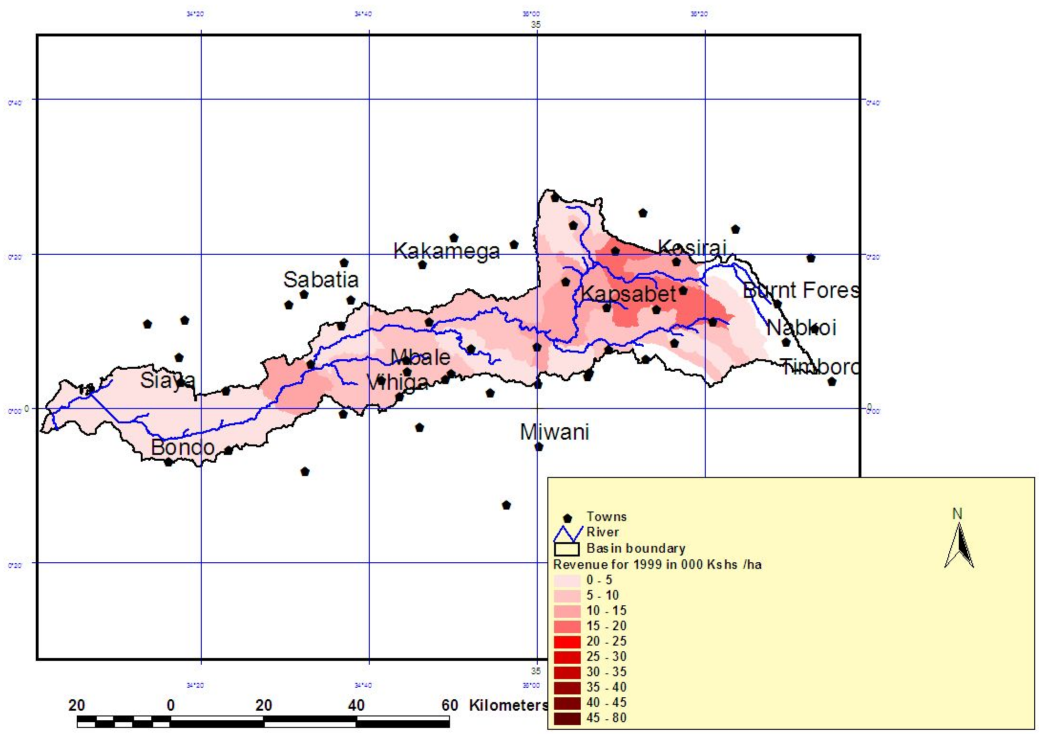

Figure 10a. Value of agricultural production per hectare per sub-basin in the Yala basin, 1999 (expressed in thousands of Kenya shillings in 2005 terms).

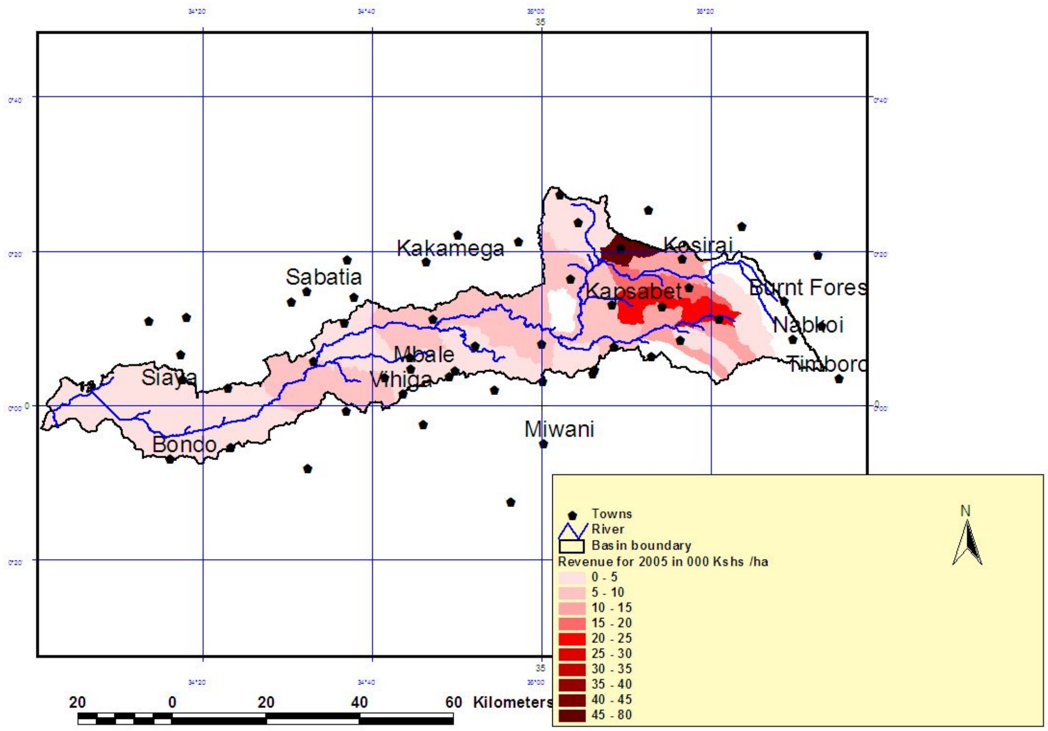

Figure 10b. Value of agricultural production per hectare per sub-basin in the Yala basin, 2005 (expressed in thousands of Kenya shillings in 2005 terms).

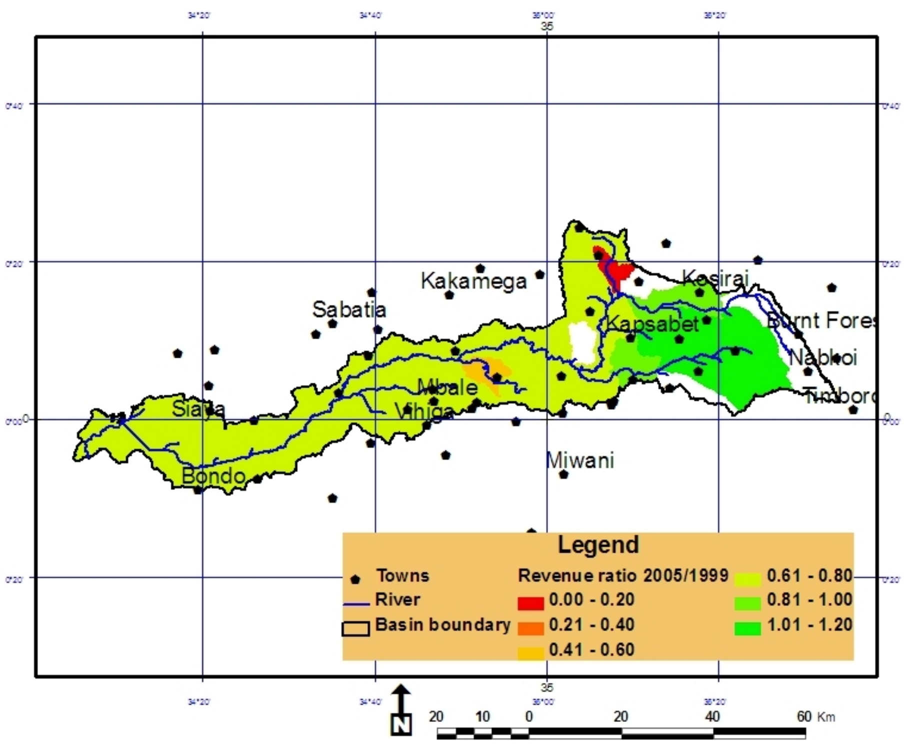

Figure 10c. Ratio of value of agricultural production per hectare in 2005 / 1999 per sub-basin in the Yala basin, 2005 (ratios less than one indicate reductions, ratios greater than one indicate increases).

3.5 Analysis of tradeoffs between value of production and sediment yield

The final result presented in this paper is the apparent spatial tradeoff between value of production and sediment yield. For each sub-basin in the two river basins, we considered the apparent tradeoff or complementarity between the value of agricultural production in 2005 and the predicted sediment yield for 2005. We present those results in two ways. First, we considered the statistical relationship, estimating a simple linear regression between them for each basin. Second, we calculated the median sediment yield and median value of production per hectare and characterized each sub-basin as having higher or lower than average sediment yield, and higher or lower than average value of production per hectare. Each sub-basin was thus identified as belonging to one of five categories: 1) low revenue and low sediment yield (shown in red); 2) low revenue and high sediment yield (shown in brown); 3) high revenue and low sediment yield (shown in dark green); or 4) high revenue and high sediment yield (shown in bright green).

Results of a linear regression analysis (not shown) show no significant relationship between sediment yield and value of agricultural production in either basin. Figures 11a and 11b display the results of the overlay of revenue and sediment yield. In Nyando, most of the sub-basins with high revenue are located in the upper part of the basin, with a roughly equal number characterized as having higher than average sediment yield. The rice irrigation area in the lower part of the basin stands out as the lowland area with high production and low sediment yield. The Yala basin has a more distinct geographic pattern, with the lowest part of the basin having low revenue and low sediment yield, the mid-altitude area having low revenue and high sediment yield, and the upper part of the basin having a high revenue and a mixture of high and low sediment yields. Again, there is no simple tradeoff between gains in agricultural production and losses of regulatory services.

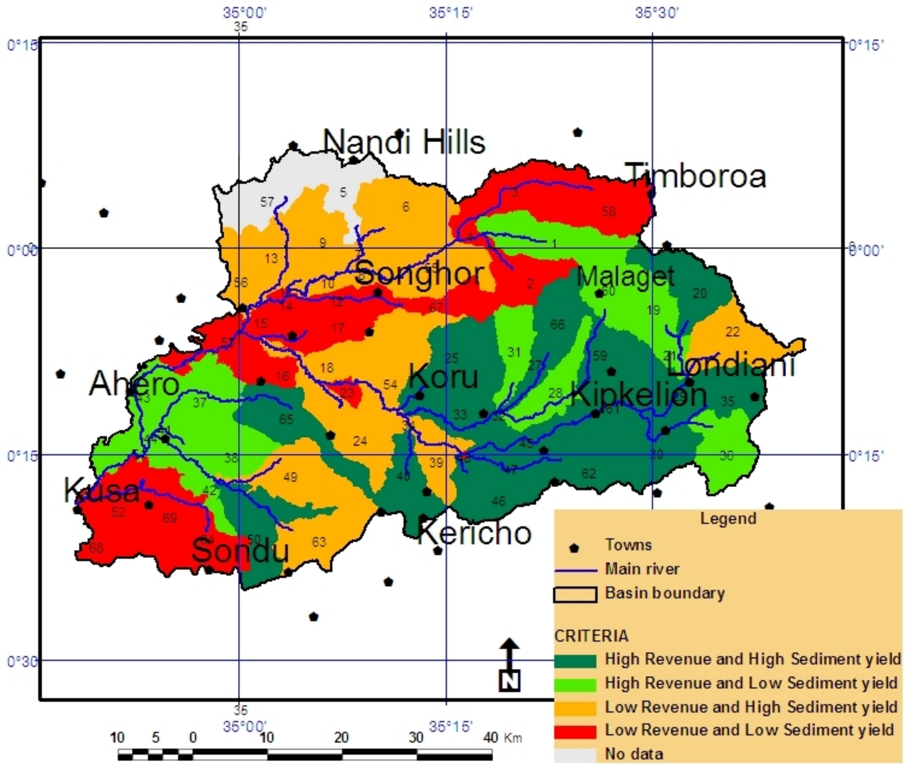

Figure 11a Tradeoffs between agricultural revenue and sediment yield, Nyando River basin, 2005.

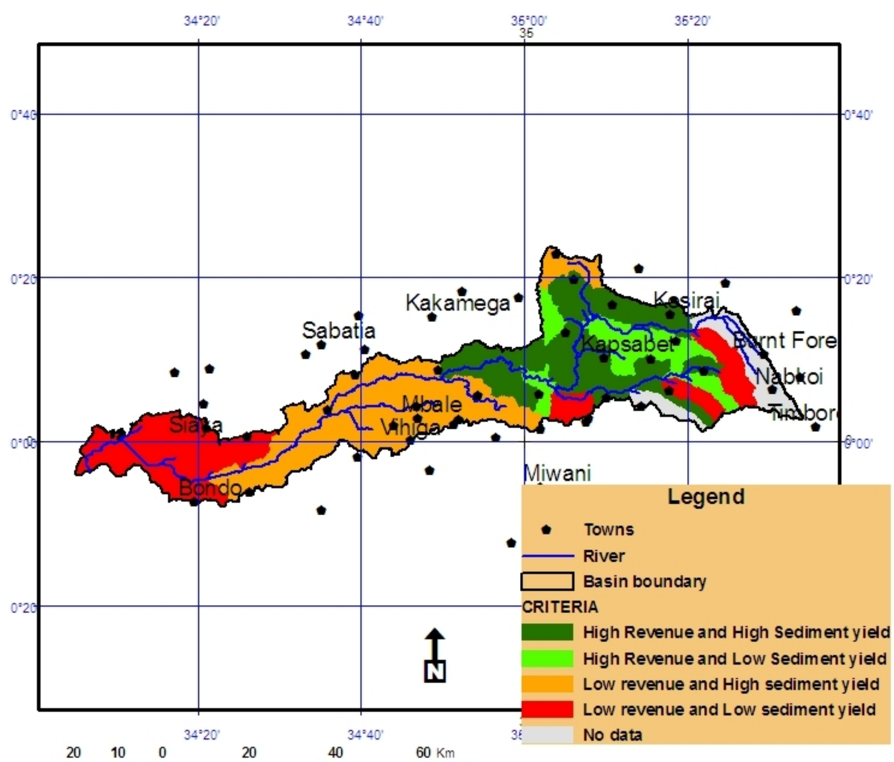

Figure 11b Tradeoffs between agricultural revenue and sediment yield, Yala River basin, 2005.

4. Conclusions

The concepts and empirical analysis of ecosystem services generated very rich insights into the spatial and temporal patterns of human – environmental interactions in the Nyando and Yala basins in the Western Kenya. Conceptually, the application of the ecosystem services concepts was relatively straightforward: value of agricultural production for the important crops was taken to be an aggregate indicator of provisioning services, sediment yield and loss of natural vegetation were taken to be aggregate indicators of loss of regulating services.
Application of the empirical approach to assess these indicators in the case study area demanded both analytical skills and data. Geographic information systems, spatially-explicit hydrological modelling, economic analysis and statistical analysis were used by the authors in an iterative manner. Multiple data sources were used including: satellite imagery, soils maps, digital elevation models and stream network information from digitized topographic sheets, climate and streamflow data from multiple sources, interpreted wall-to-wall aerial photographs taken at three time periods, and agricultural production and economic data from two time periods. A team approach was essential, with the analysis done in iterations and with review by external experts.

But the results are well worth the effort. The land use change study, based on interpretation of wall-to-wall aerial photographs, shows the dynamic nature of land use in the two basins over the last 15 years. The Nyando basin was particularly subject to tradeoffs between loss of forests and wetlands and increases in the area of maize production in the uplands and rice and vegetable production in river and lowland areas. Losses of upland forests in both basins have been matched with increases in maize production. The Nyando basin has become even more dependent on maize over the last 15 years, with accompanying drops in a large number of minor crops such as millet, pyrethrum, potatoes and wheat. There have been expansions in the farm area devoted to vegetables, rice and sorghum. There has been a particularly large percentage increase in the area of sorghum in the lower Nyando basin, perhaps because it is regarded as being a hardy food crop that is suitable for labour-constrained families affected by HIV / AIDS.

Tree crops are very important in both basins, with expansions in tea and mangoes, and contractions in coffee. The area of woodlots and hedgerows appears to be relatively stable. Tea has become one of the most vibrant sub-sectors of the Kenyan economy, with Kenya becoming one of the world's largest producers. Tea also produces relatively high revenue for farmers. Coffee, on the other hand, produces very little revenue per hectare and has been largely removed from this part of Kenya.

An agricultural sub-sector that bears additional analysis is sugarcane. Sugarcane occupies a large proportion of the mid-altitude areas of the Nyando basin and, accordingly to this study, a variable proportion of land in the Yala basin. Yet the value of production per hectare generated by sugarcane is relatively low and stagnant between 1999 and 2005. Sugarcane is known to be a crop beset by marketing problems. Can those problems be surmounted to rejuvenate the sector? Should bio-ethanol be given more serious consideration as a possible product of sugarcane? Or should mixed smallholder agriculture be encouraged to replace part of the sugarcane area?

The spatial and temporal analysis of the value of agricultural production shows a very clear relationship between altitude and value of production. In both basins, value of production is lowest in the areas near to Lake Victoria and highest in the mid-to-upper altitude areas that are suitable to mixed smallholder agriculture and tea. In real 2005 financial terms, the value of agricultural production declined in many of the lower to mid altitude parts of both basins (especially in the sugar cane areas), while it increased in the upper altitude areas adjacent to the remaining forests.

The empirical results suggest that tradeoffs between sedimentation loss and agricultural production are relatively complex. There is no evidence of a positive relationship, that sediment loss is a necessary side-effect of high production. Nor is there evidence of a negative relationship, that there are easy win-win opportunities to expand production while conserving soil. Rather, the spatial relationship is mixed -- there is a significant number of sub-basins with high production and low sediment yield and an equally large number of sub-basins with low production and high sediment yield. Reducing sediment yield may therefore be more a matter of general farm management than crop choice.

The information on the trends and trade-offs among ecosystem services is proving to have multiple values for planning and policy. Earlier versions of these results have already been shared with local and district-level officials responsible for planning, agriculture, environment and water. All expressed keen interest in the results and identified ways to use the results in their own work. The results have also been shared with private-sector officials and non-governmental organizations active in the basins who also will use the results for a variety of purposes. While these stakeholders are interested in the overall spatial and temporal patterns, they are somewhat more interested in understanding and interpreting the details, particularly the factors that might explain the marked differences in value of production from year-to-year, crop-to-crop, division-to-division or sub-basin to sub-basin. Their insights suggest that these differences are due to a combination of factors, with irrigation and maize-buying policies perhaps having greatest influence. This calls for a spatially-explicit analysis of policy.

References

Awiti A, Walsh M. 2000. Regional Assessment of Priority River Basins. In: Shepherd K, Walsh M, Mugo F, Ong C, Hansen T, Swallow B, Awiti A, Hai M, Nyantika D, Ombao D, Grunder M, Mbote F, Mungai D. *Improved Land Management in the Lake Victoria Basin: Linking Land and Lake, Research and Extension, Catchment and Lake Basin*. Final Technical Report, Startup Phase, July 1999 to June 2000. Working Paper 2000-2. Nairobi: ICRAF.

Awiti A, Walsh M, Shepherd K, Kinyamario J. 2007. Soil condition classification using infrared spectroscopy: A proposition for assessment of soil condition along a tropical forest-cropland chronosequence. *Geoderma* 143: 73-84.

Boyd J, Banzhaf S. 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics* 63: 616-626.

Bleher B, Uster D, Bergsdorf T. 2006. Assessment of threat status and management effectiveness in Kakamega Forest, Kenya. *Biodiversity and Conservation* 15: 1159-1177.

Cohen M, Shepherd K, Walsh M. 2005. Empirical reformulation of the universal soil loss equation for erosion risk assessment in a tropical watershed. *Geoderma* 124: 235–252.

Export Promotion Council of Kenya. Economic Overview - Key Economic and Social Indicators. http://www.epckenya.org/page.asp?page=ECON_OVVW&submenu=KEN_PROF&childmenu=ECON_OVVW) (Accessed June 7, 2008).

Inter-Academy Council. 2004. *Realizing the Promise and Potential of African Agriculture*. The Hague: Inter-Academy Council.

van Jaarsveld A, Biggs R, Scholes R, Bohensky E, Reyers B, Lynam T, Musvoto C, Fabricius C. 2005 . Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SAfMA) experience. *Philosophical Transactions of the Royal Society B-Biological Sciences* 360: 425-441.

Jha M, Gassman P, Secchi S, Gu R, Arnold J. 2004. Effect of Watershed Subdivision on SWAT Flow, Sediment, and Nutrient Predictions. *Journal of the American Water Resources Association* 40:811-825.

Kinaro Z. 2008. *Wetland Conversion to large-scale agricultural production; implications on the livelihoods of rural communities, Yala Swamp, Lake Victoria basin, Kenya*. Sweden: Department of Water and Environmental Studies, Linkopings University.

Kindt R, Lillesø J, van Breugel P, Nyabenge M. 2005. *Potential natural vegetation of south-western Kenya for selection of indigenous tree species: sheets 1 and 3*. Nairobi: World Agroforestry Centre.

Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Synthesis*. Washington DC: Island Press.

Mati B, Veihe A. 2001. Application of the USLE in a Savanna Environment: Comparative Experiences from East and West Africa. *Singapore Journal of Tropical Geography* 22: 138-155.

Rodríguez J, Beard T Jr., Bennett E, Cumming G, Cork S, Agard J, Dobson A, Peterson G. 2006. Trade-offs across space, time, and ecosystem services. *Ecology and Society* 11: 28. (Available from http://www.ecologyandsociety.org/vol11/iss1/art28/)

Sang J, Gathenya M, Ndegwa G. 2007. Evaluation of reservoirs as flood mitigation measure in Nyando Basin, Western Kenya, using SWAT. *European Journal of Scientific Research* 18: 231-239.

Scheren P, Zanting H, Lemmens A, 2000. Estimation of water pollution sources in Lake Victoria, East Africa: Application and elaboration of the rapid assessment methodology. *Journal of Environmental Management* 58: 235-248.

Spruill C, Workman A, Taraba J. 2000. Simulation of daily and monthly discharge from small watershed using the SWAT model. *Transaction of the American Society of Agricultural Engineers* 43: 1431-1439.

Swallow B, Onyango L, Meinzen-Dick R. 2007. Irrigation Management and Poverty Dynamics: Case Study of the Nyando Basin in Western Kenya. In: Von Koppen B, Giordano M, Butterworth J, eds. *Community-Based Water Law and Water Resource Management Reform in Developing Countries*. Wallingford, UK: CABI. P. 196-210.

Thenya T, Wassmann R, Verchot L, Mungai D, Odada E, Olago D, Ochola W, Ntiba M, Wandiga S, Gichuki N, Oyieke H. 2006. *Degradation of the riparian wetlands in the Lake Victoria basin - Yala swamp case study.* Proceedings of the 11th World Lakes Conference - Proceedings Volume 2. p. 483-494.

Verschuren D, Johnson T, Kling H, Edgington D, Leavitt P, Brown E, Talbot M, Hecky R. 2002. History and timing of human impact on Lake Victoria, East Africa. *Proceedings of the Royal Society of London Series B – Biological Sciences* 269: 289-294.

[ICRAF] World Agroforestry Centre. 2006. *Improved Land Management in the Lake Victoria Basin: Final Report of the TransVic Project.* World Agroforerstry Centre Occasional Paper No. 7. Nairobi: World Agroforestry Centre.

World Resources Institute, Department of Resource Surveys and Remote Sensing Ministry of Environment and Natural Resources, Central Bureau of Statistics and International Livestock Research Institute. 2007. *Nature's Benefits in Kenya: An Atlas of Ecosystems and Human Well-Being.* Washington DC and Nairobi: World Resources Institute

WORKING PAPERS IN THIS SERIES

1. Agroforestry in the drylands of eastern Africa: a call to action

2. Biodiversity conservation through agroforestry: managing tree species diversity within a network of community-based, nongovernmental, governmental and research organizations in western Kenya.

3. Invasion of *prosopis juliflora* and local livelihoods: Case study from the Lake Baringo area of Kenya

4. Leadership for change in farmers organizations: Training report: Ridar Hotel, Kampala, 29th March to 2nd April 2005.

5. Domestication des espèces agroforestières au Sahel : situation actuelle et perspectives

6. Relevé des données de biodiversité ligneuse: Manuel du projet biodiversité des parcs agroforestiers au Sahel

7. Improved land management in the Lake Victoria Basin: TransVic Project's draft report.

8. Livelihood capital, strategies and outcomes in the Taita hills of Kenya

9. Les espèces ligneuses et leurs usages: Les préférences des paysans dans le Cercle de Ségou, au Mali

10. La biodiversité des espèces ligneuses: Diversité arborée et unités de gestion du terroir dans le Cercle de Ségou, au Mali

11. Bird diversity and land use on the slopes of Mt. Kilimanjaro and the adjacent plains, Tanzania

12. Water, women and local social organization in the Western Kenya Highlands

13. Highlights of ongoing research of the World Agroforestry Centre in Indonesia

14. Prospects of adoption of tree-based systems in a rural landscape and its likely impacts on carbon stocks and farmers' welfare: The FALLOW Model Application in Muara Sungkai, Lampung, Sumatra, in a 'Clean Development Mechanism' context

15. Equipping integrated natural resource managers for healthy agroforestry landscapes.

16. Are they competing or compensating on farm? Status of indigenous and exotic tree species in a wide range of agro-ecological zones of Eastern and Central Kenya, surrounding Mt. Kenya.

17. Agro-biodiversity and CGIAR tree and forest science: approaches and examples from Sumatra.

18. Improving land management in eastern and southern Africa: A review of polices.

19. Farm and household economic study of Kecamatan Nanggung, Kabupaten Bogor, Indonesia: A socio-economic base line study of agroforestry innovations and livelihood enhancement.

20. Lessons from eastern Africa's unsustainable charcoal business.

21. Evolution of RELMA's approaches to land management: Lessons from two decades of research and development in eastern and southern Africa

22. Participatory watershed management: Lessons from RELMA's work with farmers in eastern Africa.

23. Strengthening farmers' organizations: The experience of RELMA and ULAMP.

24. Promoting rainwater harvesting in eastern and southern Africa.

25. The role of livestock in integrated land management.

26. Status of carbon sequestration projects in Africa: Potential benefits and challenges to scaling up.

27. Social and Environmental Trade-Offs in Tree Species Selection: A Methodology for Identifying Niche Incompatibilities in Agroforestry *[Appears as AHI Working Paper no. 9]*

28. Managing tradeoffs in agroforestry: From conflict to collaboration in natural resource management. *[Appears as AHI Working Paper no. 10]*

29. Essai d'analyse de la prise en compte des systemes agroforestiers pa les legislations forestieres au Sahel: Cas du Burkina Faso, du Mali, du Niger et du Senegal.

30. Etat de la recherche agroforestière au Rwanda etude bibliographique, période 1987-2003

31. Science and technological innovations for improving soil fertility and management in Africa: A report for NEPAD's Science and Technology Forum.

32. Compensation and rewards for environmental services.

33. Latin American regional workshop report compensation.

34 Asia regional workshop on compensation ecosystem services.

35 Report of African regional workshop on compensation ecosystem services.

36 Exploring the inter-linkages among and between compensation and rewards for ecosystem services CRES and human well-being

37 Criteria and indicators for environmental service compensation and reward mechanisms: realistic, voluntary, conditional and pro-poor

38 The conditions for effective mechanisms of compensation and rewards for environmental services.

39 Organization and governance for fostering Pro-Poor Compensation for Environmental Services.

40 How important are different types of compensation and reward mechanisms shaping poverty and ecosystem services across Africa, Asia & Latin America over the Next two decades?

41. Risk mitigation in contract farming: The case of poultry, cotton, woodfuel and cereals in East Africa.

42. The RELMA savings and credit experiences: Sowing the seed of sustainability

43. Yatich J., Policy and institutional context for NRM in Kenya: Challenges and opportunities for Landcare.

44. Nina-Nina Adoung Nasional di So! Field test of rapid land tenure assessment (RATA) in the Batang Toru Watershed, North Sumatera.

45. Is Hutan Tanaman Rakyat a new paradigm in community based tree planting in Indonesia?

46. Socio-Economic aspects of brackish water aquaculture (*Tambak*) production in Nanggroe Aceh Darrusalam.

47. Farmer livelihoods in the humid forest and moist savannah zones of Cameroon.

48. Domestication, genre et vulnérabilité : Participation des femmes, des Jeunes et des catégories les plus pauvres à la domestication des arbres agroforestiers au Cameroun.

49. Land tenure and management in the districts around Mt Elgon: An assessment presented to the Mt Elgon ecosystem conservation programme.

50. The production and marketing of leaf meal from fodder shrubs in Tanga, Tanzania: A pro-poor enterprise for improving livestock productivity.

51. Buyers Perspective on Environmental Services (ES) and Commoditization as an approach to liberate ES markets in the Philippines.

52. Towards Towards community-driven conservation in southwest China: Reconciling state and local perceptions.

53. Biofuels in China: An Analysis of the Opportunities and Challenges of Jatropha curcas in Southwest China.

54. Jatropha curcas biodiesel production in Kenya: Economics and potential value chain development for smallholder farmers

55. Livelihoods and Forest Resources in Aceh and Nias for a Sustainable Forest Resource Management and Economic Progress.

56. Agroforestry on the interface of Orangutan Conservation and Sustainable Livelihoods in Batang Toru, North Sumatra.

57. Assessing Hydrological Situation of Kapuas Hulu Basin, Kapuas Hulu Regency, West Kalimantan.

58. Assessing the Hydrological Situation of Talau Watershed, Belu Regency, East Nusa Tenggara.

59. Kajian Kondisi Hidrologis DAS Talau, Kabupaten Belu, Nusa Tenggara Timur.

60. Kajian Kondisi Hidrologis DAS Kapuas Hulu, Kabupaten Kapuas Hulu, Kalimantan Barat.

61. Lessons learned from community capacity building activities to support agroforest as sustainable economic alternatives in Batang Toru orang utan habitat conservation program (Martini, Endri et al.)

62. Mainstreaming Climate Change in the Philippines.

63. A Conjoint Analysis of Farmer Preferences for Community Forestry Contracts in the Sumber Jaya Watershed, Indonesia.

64. The Highlands: A shower water tower in a changing climate and changing Asia.

65. Eco-Certification: Can It Deliver Conservation and Development in the Tropics.

66. Designing ecological and biodiversity sampling strategies.

67. The Asian water tower: a shared resource in a changing climate and changing Asia.

68. Towards mainstreaming climate change in grassland management: Policies and practices on the Tibetan Plateau.

Who we are

The World Agroforestry Centre is the international leader in the science and practice of integrating 'working trees' on small farms and in rural landscapes. We have invigorated the ancient practice of growing trees on farms, using innovative science for development to transform lives and landscapes.

Our vision

Our vision is a rural transformation in the developing world resulting in a massive increase in the use of trees in agricultural landscapes by smallholder households for improved food security, nutrition, income, health, shelter, energy and environmental sustainability.

Our mission

Our mission is to generate science-based knowledge about the complex roles that trees play in agricultural landscapes, and to use its research to foster policies and practices that benefit the poor and the environment.

United Nations Avenue, Gigiri - PO Box 30677 - 00100 Nairobi, Kenya
Tel: +254 20 7224000 or via USA +1 650 833 6645
Fax: +254 20 7224001 or via USA +1 650 833 6646
www.worldagroforestry.org