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Using an ecosystems approach for securing water and land resources in the Upper Tana Basin

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1. Introduction

Ecosystem degradation has the highest impact on the Tana River's life supporting functions and ecosystem services (ESS) in the Upper Tana Basin, which in turn impacts several users downstream. Within this river basin, several land use practices result in runoff discharge and not recharge. Agriculture serves as a non-point source for sediment and chemical pollutants while some of the point sources that discharge excessive sediment include stone quarrying sites located near river courses. Other sources are linked to infrastructural development like steep road embankments and dump sites as well as large tracts of exposed soil surfaces. Human activities like farming on steep hill slopes with poor ground cover and unmanaged storm water drains have led to major erosion and landslides occurring within the watershed.

Through the Nairobi Water Fund, the Nature Conservancy is partnering with CIAT as well as other partners to find shared solutions to shared challenges in the watershed in a bid to create a brighter future for Nairobi's water. Rapid changes have been taking place in this region over the last three decades. We posit that a landscape approach that considers a wide range of beneficiaries and considers how costs and benefits are distributed equitably across the landscape will provide feasible solutions. We need to support sustainable land management of onsite stewards (upstream local resource users) while providing guidance and informed investments for offsite beneficiaries (downstream private sector stakeholders and urban dwellers) in the form of targeted upstream interventions. For this study, we focus on water-related services; specifically such as avoided sedimentation that impacts drinking water supply, hydropower supply, water purification as well as erosion control.

In partnership with The Nature Conservancy (TNC), CIAT is using ecosystem based approaches that mitigate sedimentation and erosion in the predominantly rural upstream watersheds of the Upper Tana River Basin while providing good quality and adequate quantity of water for downstream urban dwellers of Nairobi. Numerous other private sector and policy entities are involved in this initiative. In order to characterize this system, we present two watersheds (50 km apart) in the Upper Tana River Basin and pose the question: if an ecosystem based approach were taken, how could we secure water and land resources for sustainable agricultural productivity within these landscapes?

1.1 Study Objectives:

The overall aim of the project was to use readily available data sets coupled with targeted field studies to assemble evidence for key indicators of ESS sustainability and livelihood strategies in two sub-basins of the Tana Basin: Nyeri and Thika. Three specific research objectives were:

i) Evaluate past and present landscape land cover/land use changes and how human activity has contributed to water and land degradation (specifically sedimentation) and thus a decline in ESS;
ii) Quantify and map the flow of ESS through modeling tools best suited to analyze multiple services and objectives in landscapes;
iii) Identify and assess resource investment trajectories and how they relate to water and land degradation under current and future climate landscape and climate conditions.

2. Key study findings

1. Change detection in the two watersheds evaluation showed that most of the land cover classes experienced both gains and losses during the 2001 – 2013 period. The net change generated showed that tea and cereals were the biggest gainers, while forest and grassland were the biggest losers in terms of the area occupied. However, spatially the two watersheds are very dynamic with agricultural categories transitioning back and forth in the lowlands and conversion from natural areas mostly occurring on the boundaries of protected areas.
2. Climate suitability maps revealed that more areas will become suitable for both maize and beans, in particular to the west of the two watersheds under consideration, which is an area currently under tea production. This has implications as conversion from tea cover may increase overall runoff and reduce sediment retention in these areas. Areas currently covered by coffee, vegetables and cereals will become more suitable for tea. Conversion of food crops to tea, an important cash crop in the region, may have a negative impact on food security.
3. Hydrological assessments revealed that consideration of point sources outside of agriculture is critical to assessing overall landscape contribution of sediment in streams.
4. Hydrological modeling and land use scenario generation also revealed that conversion of tea lands to agriculture and coffee will generate higher sediment loads to streams. Land cover classes covered by tea in both watersheds had the lowest sediment yields while land use under agricultural crops generated much higher sediment.
5. Without an adequate emphasis on maintenance and implementation of sustainable land management (SLM) practices in the landscape, land use changes will likely exacerbate the impact of sediment deposition in rivers and streams, which may further be accelerated by the projected 5% increment in future rainfall.
6. Scenario generation revealed that tradeoff analysis between environmental integrity and population food security needs to be conducted in order to provide sustainable intervention options for both on-site and off-site beneficiaries under these changing landscapes.

3. Methods:

3.1 Sites description and study justification

This study was conducted in Kenya within the Upper Tana River Basin within two sub-basins: Nyeri and Thika. For WLE Regional focus, this area falls under the Nile/East African Region. The general characteristics for both watersheds (Figure 1) under consideration are presented in Table 1.

Table 1. Nyeri and Thika watershed characteristics

Characteristics	**Nyeri**	**Thika**
Land area (ha)	145,849	81,605
Population density* (per km^2)	197	329
Absolute poverty* (%)	31	48
Predominant soils	Ferric Acrosols	Orthic and Ferric acrosols
Predominant land use	Agriculture and mixed forest	Mixed forest, Coffee and Tea
Elevation (m)	2265	2190
Predominant slope (%)	10-20	20-40
Long term average rainfall (mm)	850-1600	950-1100
Mean long term temp (^oC)	20	18

**Based on district wide data (District Development Plans: 2002-2008)*

The Tana River is the largest river in Kenya and begins in the central Kenya highlands and flows for 800 kilometres to the Indian Ocean. The Tana River basin is divided into two distinct agro-ecological zones; the Upper Tana basin which receives more rainfall and is the predominant source of water while the Lower Tana basin is drier, flatter, and completely depends on the upper regions for river water flow. The River serves as an indispensable source of water for crops, livestock, wildlife and environmental flows. It is also used to produce hydroelectricity and it supplies domestic and drinking water to Kenya's capital Nairobi and for irrigation water to several large public schemes in Kenya. However, the reservoir capacity in the Middle Tana is threatened by sediment generated from the intensively farmed areas in the Upper Tana catchment. Ecosystem degradation has resulted in unpredictable flows of water amidst rising demand. The degradation is caused by changes in land use, and the expansion of commercial and subsistence farming activities especially in the Upper Tana catchment area.

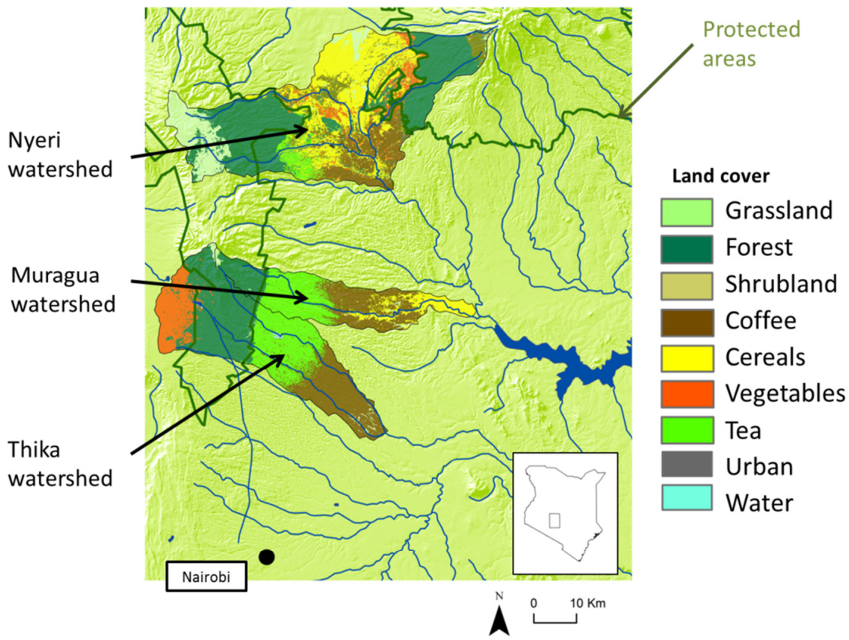


Figure 1. The location of the priority watersheds identified by The Nature Conservancy and land cover classification conducted in 2013. These watersheds are critical as they provide 90% of Nairobi's water and contribute to 66% of Kenya's electricity supply through downstream hydroelectricity generation. Protected area boundaries are shown in green.

3.2 Workflow framework

The current challenge is that upstream dynamics are contributing to increased sedimentation and degraded water quality in the streams that supply downstream urban dwellers. In a bid to provide feasible interventions, we present a stepwise procedure of methods that were used to characterize the system as a means towards providing viable recommendations for securing water and land resources in the Basin (Figure 2). The characterization took the form of land use change assessments, crop suitability modeling, and hydrological modeling followed by scenario assessment of the two watersheds in the Basin.

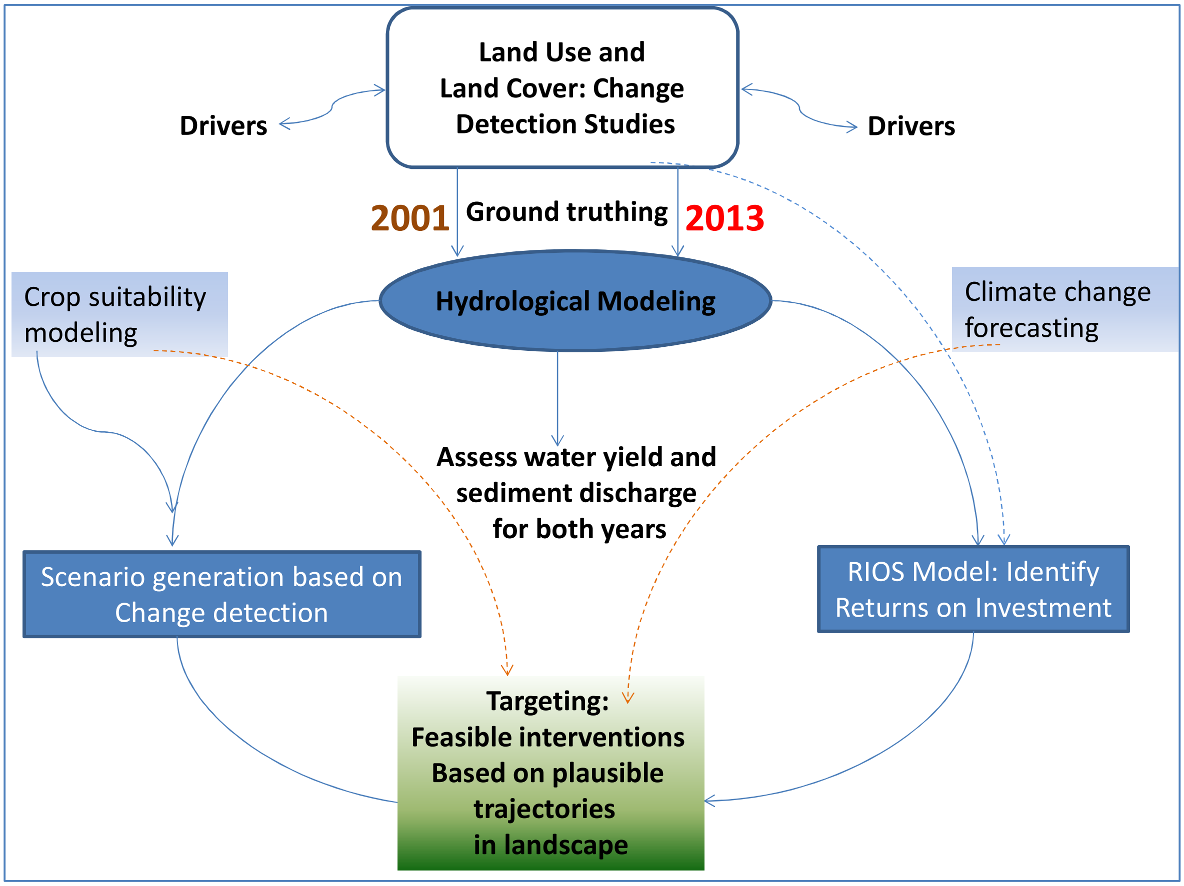


Figure 2: A conceptual model that portrays the methods used in this study.

3.3. Methods and tools towards meeting research goals (Figure 1):

i) Conducted detailed assessments of land use and land cover (LULC) change in the region. This was done as a preliminary step before building a detailed social-ecological inventory (SEI) with multiple actors; the latter part is still on-going given the big spatial coverage of the study area (being conducted through CIAT's WLE activities). A 'survey instrument' was developed with partner input and this will help in characterizing the bundles of ESS. Land use and land cover change detection was conducted using Arc GIS 10.1; ENVI 5.0 and IDRISI Selva. Extensive field ground truthing helped verify LULC change results (Addresses Objective i).

ii) Crop suitability modeling was conducted using Eco-crop Model to investigate likelihood scenarios of future agricultural land use change under climate change (Addresses research objective i).

iii) Through partnership collaboration, in-stream measurements were taken and in-situ monitoring was conducted with the use field data loggers for collecting data on water quality and aquatic habitat status (e.g. dissolved oxygen and turbidity). Considering the short project time-frame, this activity is still on-going and will be used to inform longer term impacts of current land use and future land use changes (Addresses research objectives I and ii).

iv) The Soil and Water Assessment Tool (SWAT model) was used to assess impacts of erosion and sedimentation associated with the land use change (Addresses research objectives # i, ii and iii).

v) We utilized geospatial and bio-economic tools to map the bundles of ESS (ArcGIS Spatial Analyst and Arc-Hydro and InVEST) to quantify, model and assess scaling-up of multiple services. The Resource Investment Optimization System (RIOS) tool was used to determine where specified sustainable land management interventions could be implemented to yield the greatest returns in erosion control. This component is still on-going and being refined with incoming field datasets. This analysis will further identify and assess ecosystem services for different livelihood trajectories and show how they relate to water and land degradation under current and future landscape and climate conditions (Addresses research objective iii).

4. Land use and land cover change detection

Based on land cover change detection, just under half of both watersheds were covered in forests in 2001 and 2013 (Figure 3) and this is predominantly found within protected areas. In Nyeri, the area of cereals increased by 8% and tea by 1%. Forest and grassland decreased by 4% and 3% respectively. In Thika, tea increased by 3% but grassland, forests and vegetables decreased by 1%, 1% and 2% respectively. Despite only small changes in overall area of different land cover, the landscape is highly dynamic with rapid interchange between land cover categories. All cover categories have experienced loss and gain (Figure 4a) across the two watersheds.

Spatial mapping of transitions between 2001 and 2013 show where there have been gains and losses of natural areas to agricultural categories (Figure 4b) and which categories have replaced each other across the landscape (Figure 5). There have been very few transitions within protected areas. Transitions from natural areas to cereals and vegetables have occurred across large areas on the boundaries of protected areas (Figure 5). Fragmented areas of forest within the tea zones have largely been converted to tea cropping in both watersheds. Within the coffee zones, largely in Thika watershed, homogenization of crops from cereals and vegetables to coffee has occurred. In Thika, large areas that were formerly coffee and other agricultural crops have been converted to tea. This has also been observed in the south-west region of the Nyeri watershed which was the tea-growing area in this watershed. However, in Nyeri new tea areas have occurred on the edge of forest boundaries replacing forest. Cereals covered a much larger extent of Nyeri in 2013 compared to 2001. The land cover mapping showed no substantial coverage of cereals being grown in Thika has occurred.

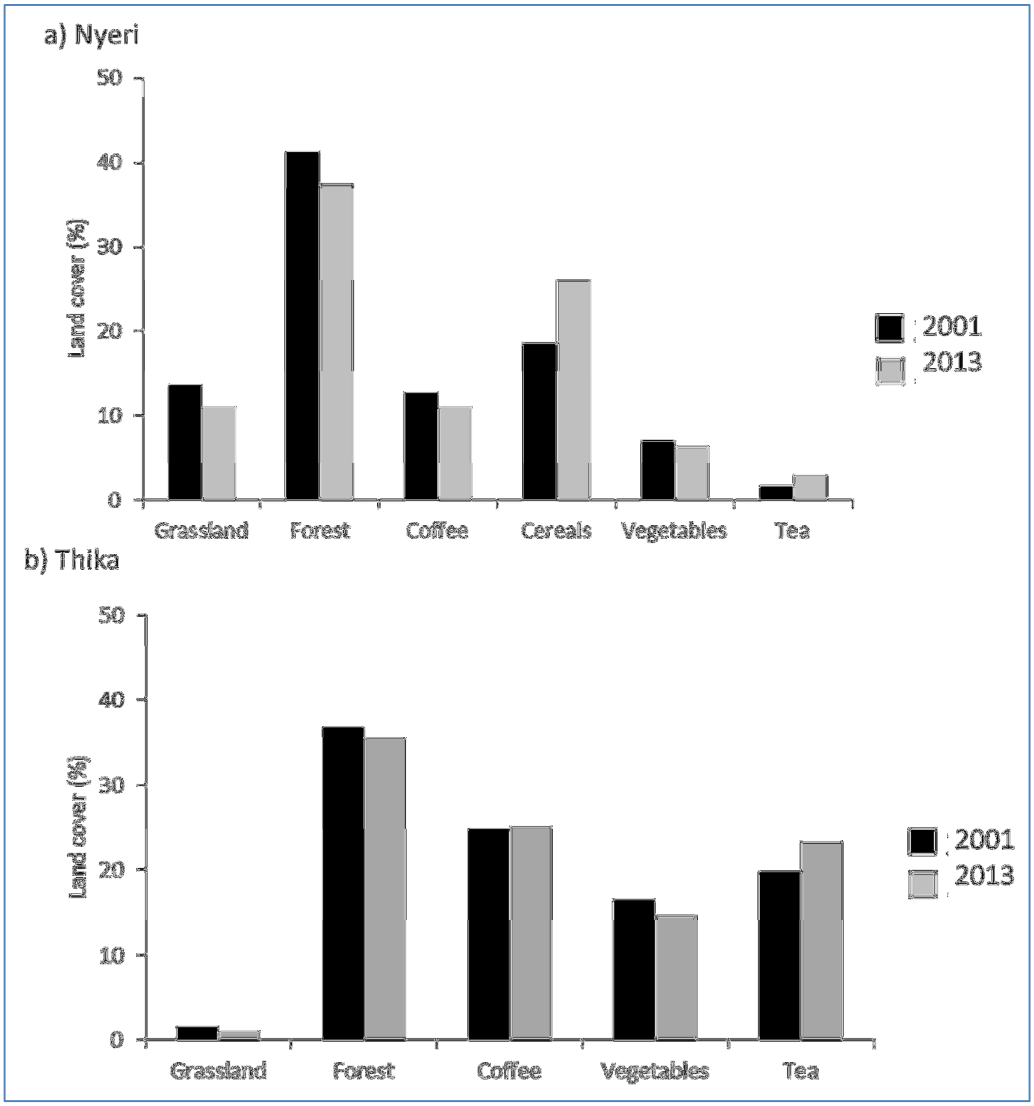


Figure 3. Area (%) of major land cover categories in Nyeri and Thika watersheds in 2001 and 2013 (excluding urban, water and shrubland).

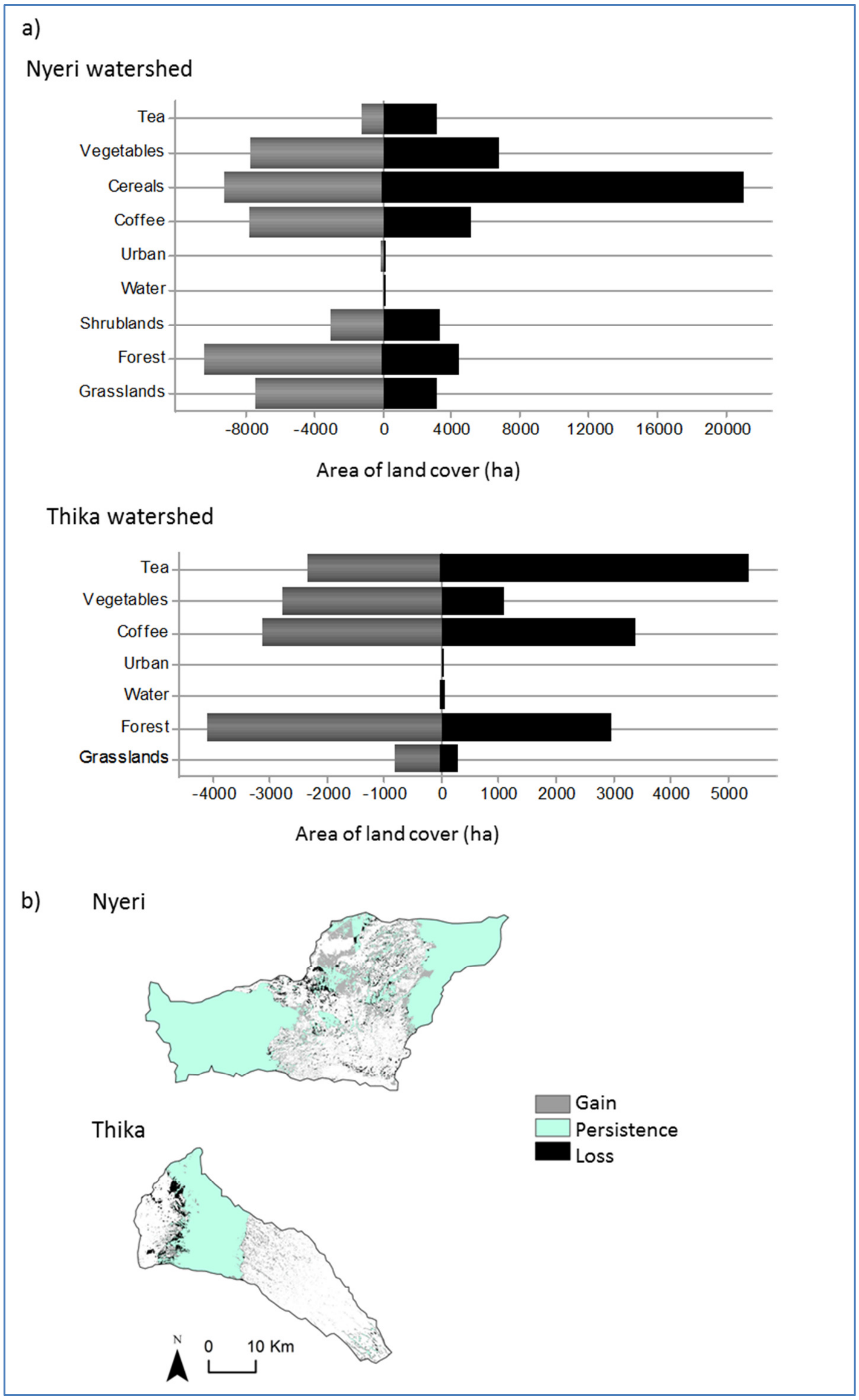


Figure 4. Changes (gains and losses) in area (ha) across all land cover categories in Nyeri and Thika watersheds between 2001 and 2013 (a). Map showing where losses from natural categories (forest, grassland, shrubland) to agricultural categories (coffee, cereals, vegetables, tea) and gains from agricultural to natural categories have occurred (b). Persistence represents any natural area that remained unchanged between 2001 and 2013. The white background represents agricultural areas that did not transition to natural areas. Protected areas are included in this analysis.

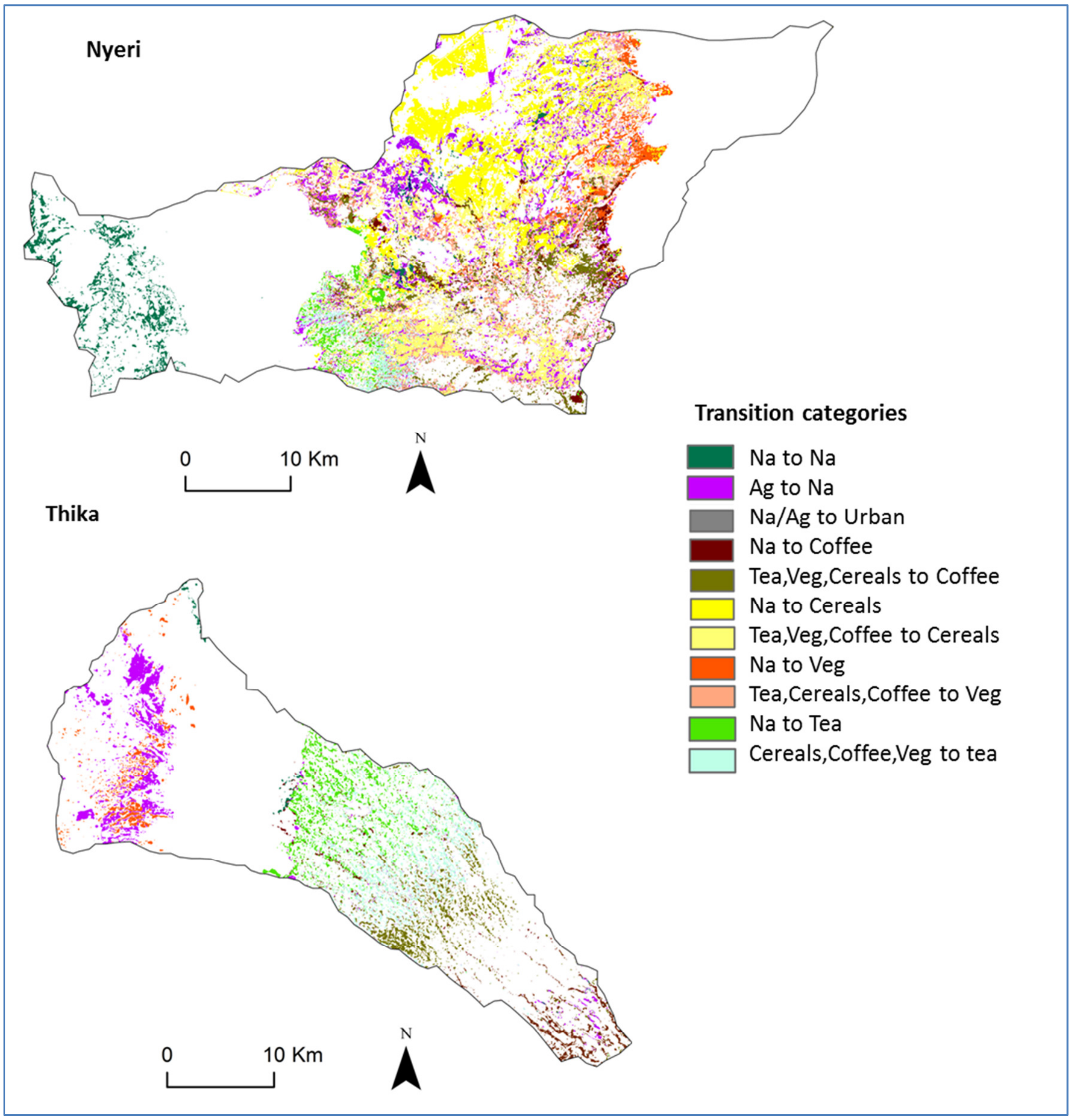
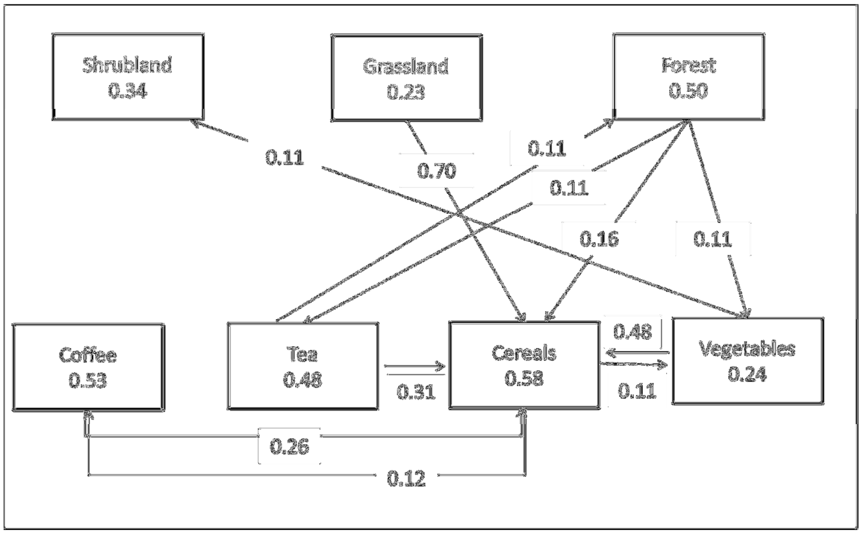


Figure 5. Map showing the dynamics of natural land cover categories (forest, grassland, shrubland) to agricultural categories (coffee, cereals, vegetables, tea) across the two target watersheds between 2001 and 2013. Na = natural (forest, grassland, shrubland); Ag = agricultural; Veg = Vegetables. Categories are combined to show combined transitions of natural and agricultural categories to other single categories. The white background represents unchanged zones.

Transition matrices can be used to investigate the proportion of land cover category that either stayed the same or transitioned to another category. Transitions calculated for all areas outside of protected areas show that most natural categories are unstable with 50% and lower remaining unchanged in both Nyeri and Thika (Figure 6, Table 2). Agriculture categories in Nyeri watersheds are also dynamic, with a large proportion of each agricultural land cover transitioning to another agricultural land use between 2001 and 2013 (Figure 6a). In the Thika watershed, tea, coffee and vegetable land cover were more persistent, with 73%, 72% and 72% of their area respectively, staying the same over the time period (Figure 6b).

a) Nyeri watershed



b) Thika watershed

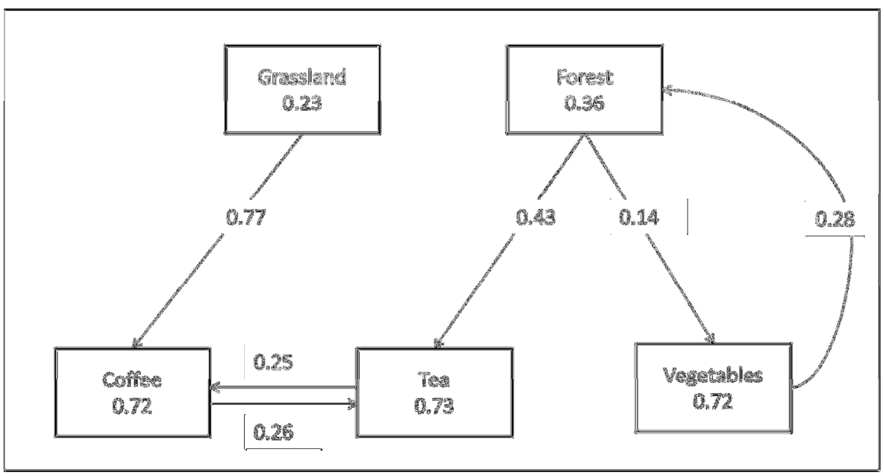


Figure 6. The proportion of land cover categories transitioning to other categories (represented by arrows) and the proportion that remained unchanged (represented by the figures inside the box) between 2001 and 2013 for Nyeri (a) and Thika (b) watersheds outside of protected areas. Only transitions above 0.10 are shown.

Table 2. Transition probability matrices calculated for all land cover categories for Nyeri and Thika watersheds outside of protected areas. The matrices show the proportion of the landscape that remained unchanged (bold values) and the proportion of the landscape that changed from one cover category to any other cover category, between 2001 and 2013 (excluding water and urban areas).

Nyeri	Grassland	Forest	Shrubland	Coffee	Tea	Cereal	Vegetable	Urban	Water
Grassland	**0.56**	0.03	0.03	0.00	0.00	0.38	0.00	0.00	0.00
Forest	0.06	**0.71**	0.01	0.04	0.04	0.07	0.06	0.00	0.00
Shrubland	0.02	0.02	**0.49**	0.00	0.00	0.42	0.04	0.00	0.00
Coffee	0.00	0.09	0.01	**0.52**	0.03	0.25	0.10	0.00	0.00
Tea	0.00	0.12	0.00	0.06	**0.48**	0.31	0.03	0.00	0.00
Cereal	0.03	0.06	0.05	0.12	0.05	**0.58**	0.11	0.00	0.00
Vegetable	0.01	0.08	0.10	0.09	0.00	0.47	**0.25**	0.00	0.00
Urban	0.00	0.03	0.00	0.00	0.00	0.47	0.06	**0.43**	0.00
Water	0.31	0.00	0.00	0.00	0.00	0.69	0.00	0.00	**0.00**

Thika	Grassland	Forest	Shrubland	Coffee	Tea	Cereal	Vegetable	Urban	Water
Grassland	**0.35**	0.02	0.00	0.62	0.00	0.00	0.00	0.00	0.00
Forest	0.01	**0.74**	0.00	0.02	0.16	0.00	0.07	0.00	0.00
Shrubland	0.13	0.13	**0.00**	0.13	0.13	0.13	0.13	0.13	0.13
Coffee	0.01	0.01	0.00	**0.72**	0.26	0.00	0.00	0.00	0.00
Tea	0.00	0.01	0.00	0.25	**0.73**	0.00	0.00	0.00	0.00
Cereal	0.13	0.13	0.13	0.13	0.13	**0.00**	0.13	0.13	0.13
Vegetable	0.00	0.31	0.00	0.00	0.00	0.00	**0.68**	0.00	0.00
Urban	0.00	0.10	0.00	0.00	0.00	0.00	0.07	**0.83**	0.00
Water	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	**0.85**

5. Crop suitability modeling

The Ecocrop Model (Hijmans et al. 2001) was used to predict the current and future suitability of major crops found in the Upper Tana. Results were used to indicate where the suitability of the various crops would increase or decrease as a factor of the climate. The crop suitability modeling revealed that more areas will become suitable for both maize and beans, in particular to the western region of the two watersheds which is an area currently covered by tea. This provides a potential future scenario that the lower half of the tea area is replaced by maize and beans. This has implications on the overall runoff and sediment retention in the landscape (Figure 7).

Areas covered by coffee and forest in the Nyeri watershed are likely to become more suitable for tea production. In addition, in the Nyeri watershed, the area currently covered by grassland and shrubland will become more suitable for cereals. Therefore, another potential scenario is replacement of shrubland and grassland by cereals. From the land cover change detection previously done; this second transformation is already apparent. With regard to the lower watershed (Thika), the suitability for the cereals class appears stable, with the above noted expansion into the tea areas.

For coffee, the area suitable for coffee will increase in both watersheds (See Figure 7). This increase in suitability appears higher in the Thika watershed, where areas currently under tea appear to be becoming more suitable for coffee. A potential scenario in this area is the replacement of the upper half of the tea by coffee.

For tea, the lower altitude regions of the two watersheds will become more suitable.. This could generate a scenario where tea production expands in to areas where coffee, cereals and vegetables are currently grown. However, the altitude requirements for tea may prevent the expansion of tea into this area.

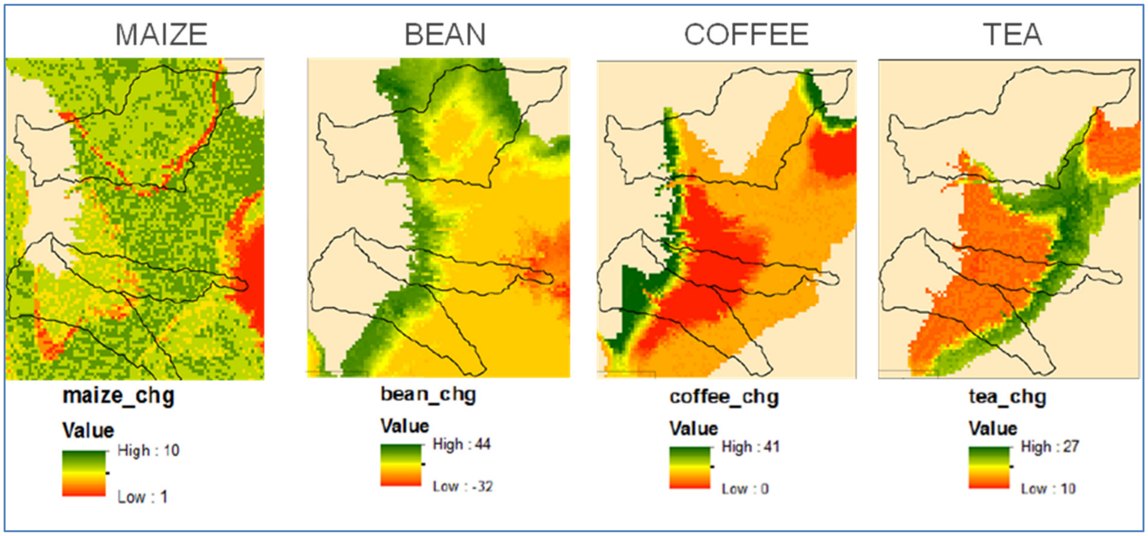


Figure 7. Maps showing changes in crop suitability (expressed as a percentage) for maize; beans; coffee and tea for the priority watersheds under climate change predictions. Future climate scenarios were generated by taking the mean value from an ensemble of GCM's which generated the climate up to the year 2050.

6. Hydrological modeling

The 2013 land use for both watersheds was run in the SWAT model and the model was calibrated for flow and sediment. Sensitivity analysis, calibration and validation were conducted. Model performance was fairly good based on both the observed and simulated flows (Figure 8) and7) with the Nash-Sutcliffe coefficient of 0.60 (Figure 9). Model accuracy is being enhanced with field flow data generated from in-stream water quality monitoring and that received from CIAT's collaborating partners.

Land use layers for the years 2001 and 2013 were simulated with the SWAT model in order to compare and contrast water yield, sedimentation and runoff between this 12 year duration. Model results of the aforementioned variables revealed that for both watersheds, there was a slight reduction in water yields (Figure 10A). On the contrary, there were observed increases in sediment yields of 31% and 40% for Nyeri and Thika watersheds respectively (Figure 10B) while runoff values for Nyeri increased by 9% with a decrease in the Thika watershed by 15% (Figure 10C). The rainfall comparison over this duration was not significantly different (Figure 10D).

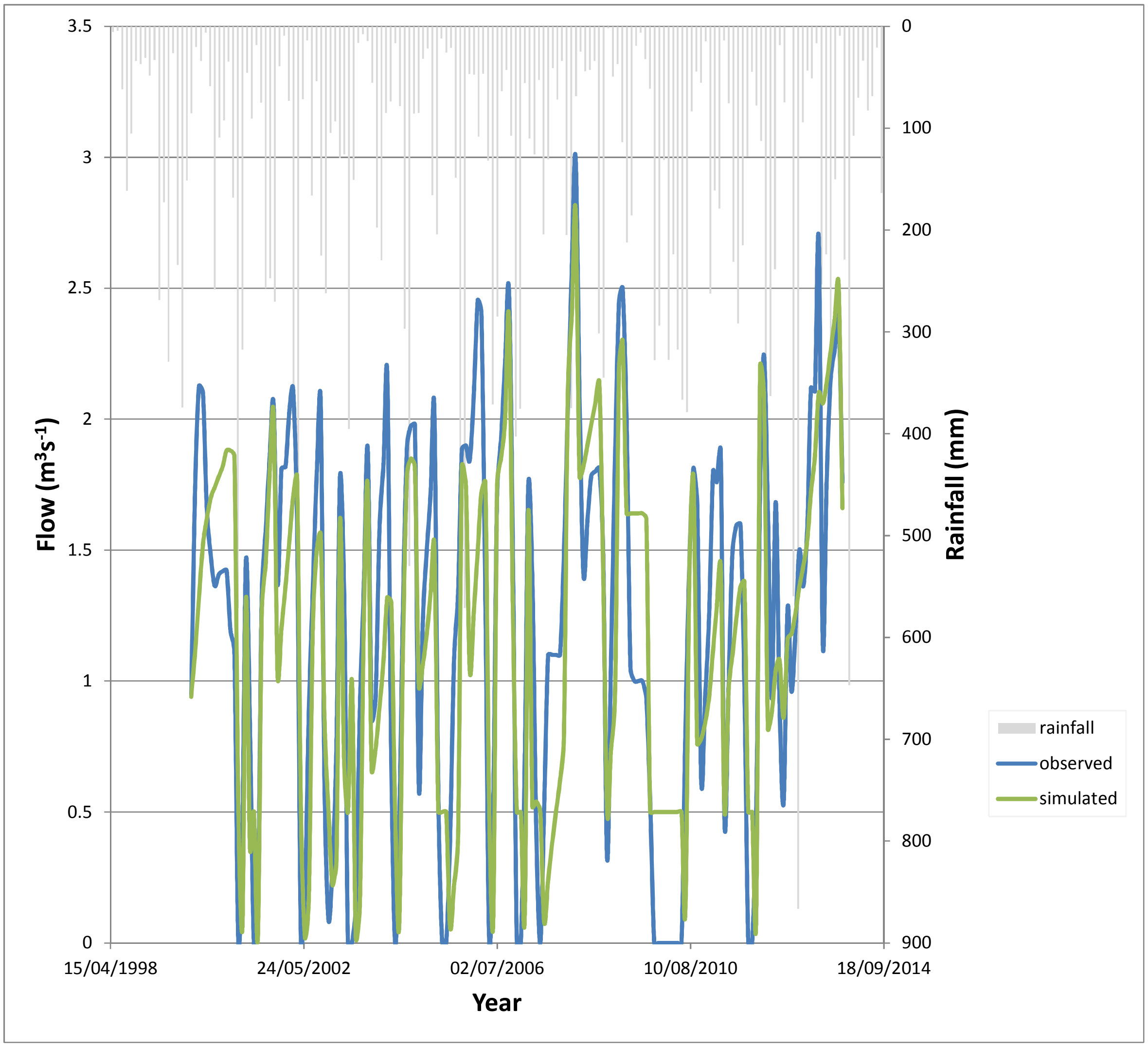


Figure 8. Observed and simulated flow regimes and rainfall trends for the Nyeri watershed between 2000 and 2013.

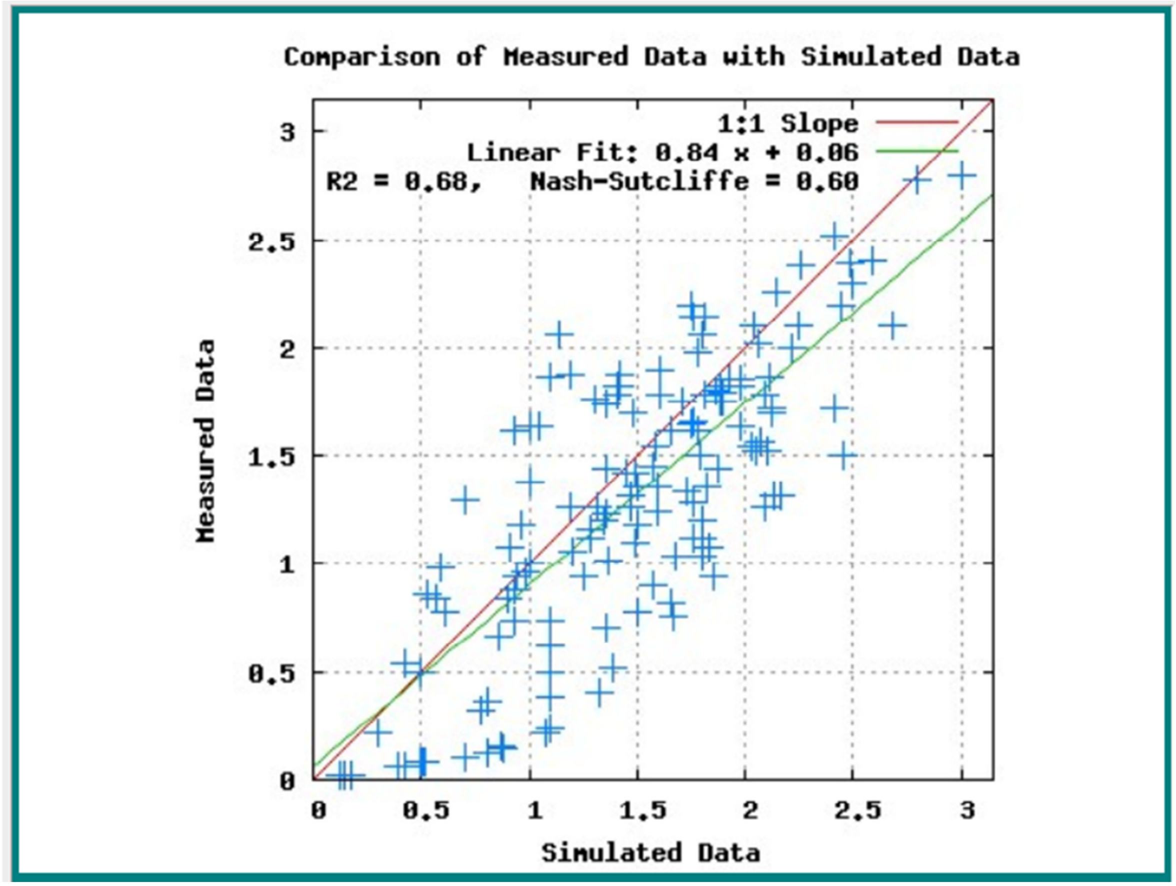


Figure 9. Observed and simulated flow regimes and rainfall trends for the Nyeri watershed between 2000 and 2013.

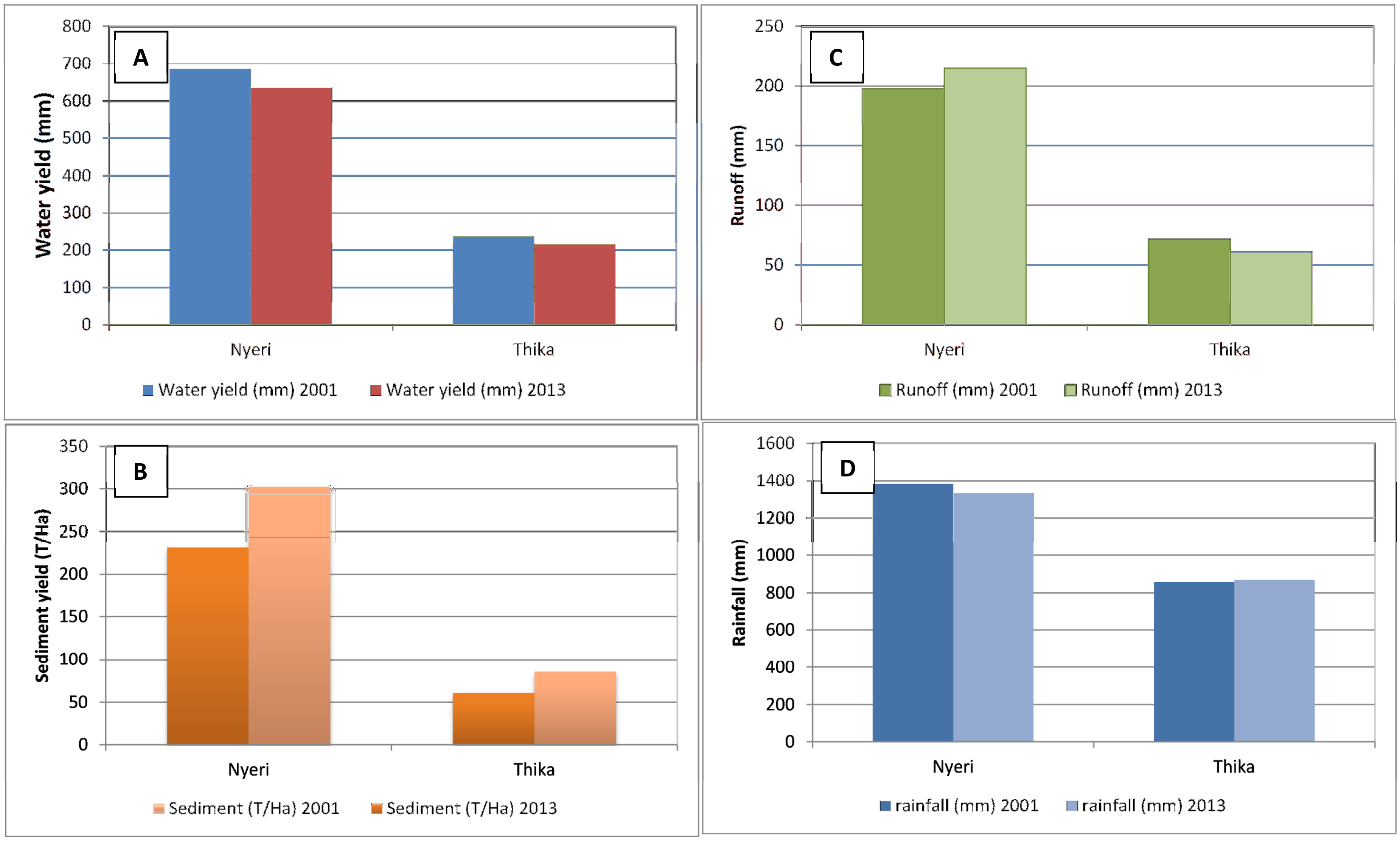


Figure 10. Comparisons of water yield, sediment yield, runoff and rainfall between 2001 and 2013 for the Nyeri and Thika watersheds

Scenario generation: Combining insights from the land use change detection and hydrological outputs, a scenario assessment was conducted within the SWAT model using the land use update tool (LUP Update) so that shifts in land use area could be changed during each model run to ascertain the impact of land use changes on the sediment yield within each watershed. This yielded feasible change scenarios based on likely future trajectories of transition. The scenarios generated included:

- Scenario 0: Where quarrying as an open point source was considered
- Scenario 1: 60% of the area covered by tea is replaced by coffee
- Scenario 2: 60% of the area covered by tea replaced by agricultural crops such as cereals and vegetables
- Scenario 3: 40% of the agricultural crops area is replaced by tea

Scenario 0: Using the 2013 land use layer, an additional layer of quarries based on ground truthed data was included as a point source into the hydrological modeling. Model outputs were compared before and after inclusion of quarries (Figure 11A). In the Nyeri watershed there was an additional 78.7 T/Ha average sediment yield, which is an additional 26% increment in sediment yield. No quarries were recorded for the Thika watershed (Figure 11A). Results from the inclusion of quarries in the analysis suggest that upstream contributions of sediment extend beyond agriculture, with substantial amounts coming from quarries This suggests that targeting of interventions needs to include other components other than agriculture within the landscape, in addition to farming land uses, which calls for inclusive engagement of other stakeholders in the mining sectors to achieve creative solutions that result in tangible impact.

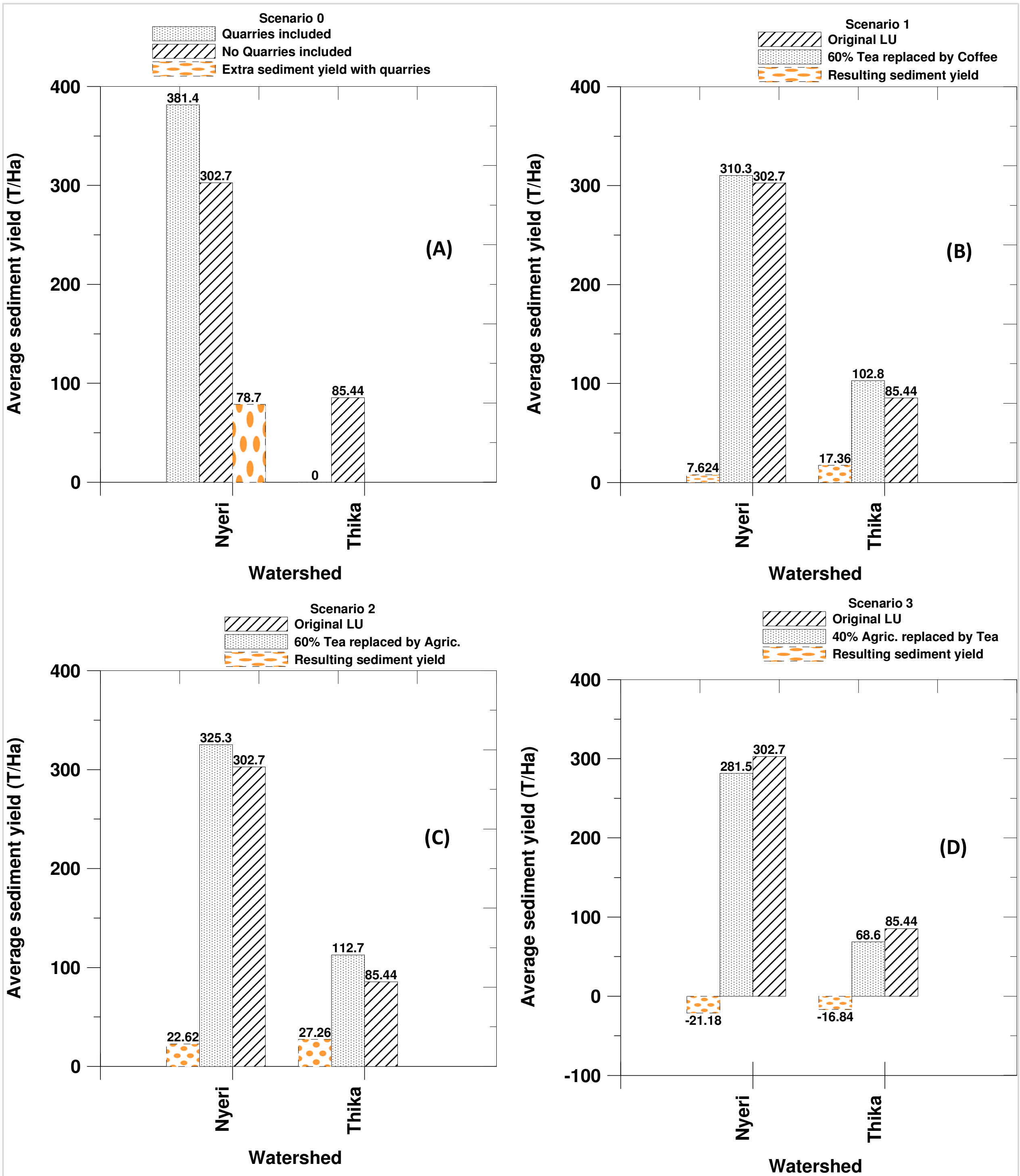


Figure 11. Scenario generation based on the 2013 land use layer for both Nyeri and Thika watersheds

Scenario 1: Using prior information generated from crop suitability trends and change detection studies, scenario 1 has 60% of land area occupied by tea replaced by coffee for both Nyeri and Thika watersheds for the 2013 land cover layer. For Nyeri, this resulted in an increase in sediment yields of about 7.6 T/Ha and 17.4 T/Ha for Thika, which are approximate increases of 3% and 20% respectively. Masking these differences are the acreages of tea and coffee in each of these watersheds. Nyeri has little tea coverage while Thika has substantial land area under tea and coffee (also see Figure 3). Scenario 1 reveals that transition from tea to coffee will increase sediment yields, an aspect that can be exacerbated if agricultural crops are included as intercrops as is done commonly (Figure 11B).

Scenario 2: Using prior information generated from crop suitability trends and change detection studies, scenario 2 has 60% of land area occupied by tea being replaced by agricultural crops specifically maize and beans for both Nyeri and Thika watersheds for the 2013 land cover layer. For Nyeri, this resulted in an increase in sediment yields of about 23 T/Ha and 28 T/Ha for Thika which approximates to increments of 8% and 31% respectively. This scenario reveals that transition from tea to agricultural crops will have substantial impact on sediment yields (Figure 11C).

Scenario 3: Using prior information generated from crop suitability trends and change detection studies, scenario 3 has 40% of land area occupied by agricultural crops being replaced by tea for both Nyeri and Thika watersheds for the 2013 land cover layer. For Nyeri, this resulted in a decrease in sediment yields of about 21 T/Ha and 17 T/Ha for Thika, which approximates to reductions of about 7% and 20% respectively. This scenario reveals that transition from tea to agricultural crops will have substantial impact on sediment yields (Figure 11D). This scenario introduces an interesting dichotomy: if emphasis is put on sediment reduction with replacement of agricultural crops with tea, the upstream farmers face reduction in food production though in the long term food production may increase as a result of enhanced environmental integrity. In some cases the food production may not necessarily increase, but farmers would earn enough from the proceeds of tea to be food secure. There are temporary trade-offs that need to be considered in terms of short term benefits (mainly for upstream rural dwellers) as opposed to longer term benefits (for environmental integrity). These are aspects that offsite downstream urban beneficiaries may need to consider when planning on the sustainability of the endowment Water Fund.

7. Resource Investment Optimization

Increasing the uptake and adoption of sustainable land management (SLM) interventions has been proposed by local partners working in the region as one solution to mitigate soil erosion and sedimentation in agricultural areas in the shorter term (within the next ten years). In general, building on existing and on-going practices will increase the adoption and long-term implementation of these interventions. To mitigate soil erosion and sedimentation in each watershed, different options for sustainable land management (SLM) interventions exist. TNC has existing plans to initiate a funding mechanism (Water Fund) to increase the adoption of SLM interventions across the watershed and would require investment to generate the funds. For investors, who in general will be downstream beneficiaries of reduced soil erosion and sedimentation, the most important priority is that investments will be spent on SLM interventions in areas that yield the greatest returns in erosion control. To investigate this, a preliminary analysis was conducted to determine where specified sustainable land management interventions should be implemented to yield the greatest returns in erosion control in the Nyeri and Thika watersheds.

The Resource Investment Optimization System (RIOS) software tool was developed by the Natural Capital Project (NatCap) (in collaboration with others) for prioritizing investments, especially for water related ecosystem services (RIOS 2013). Currently only the Investment Portfolio Advisor module is available and this uses biophysical and social data, budget information and implementation costs to produce maps that show what is likely to be the most efficient set of investments that can be made, given a specific budget (Vogl et al. 2013). RIOS was used to investigate where in Nyeri and Thika watersheds SLM interventions could be implemented for the most impact with a specified budget. A target budget has been specified by TNC for the ten year duration of the Water Fund. Two investment prioritization scenarios were investigated:

(1) Where should SLM interventions be targeted during an initial two year pilot project phase;

(2) Where should SLM interventions be targeted during the ten year duration of the Water Fund. The type of SLM interventions have already been identified by local partners in each watershed. For Nyeri these include riparian restoration, terracing and grass strips for the pilot project, with reforestation added during the ten year project. For Thika these include reforestation, terracing and grass strips.

7.1 Methodology modeling with RIOS

7.1.1 Setting objectives

In RIOS, multiple ecosystem service objectives can be specified and these objectives are the outcomes that the funding aims to achieve through its investments (Vogl et al. 2013). Here two objectives were chosen: (1) soil erosion control for drinking water and (2) soil erosion control for reservoir maintenance. For these objectives, RIOS requires the following biophysical and spatial information: current land cover; downslope retention index; upslope source; riparian continuity; rainfall erosivity; soil erodibility; soil depth and beneficiaries. The background theory of these requirements is discussed in the RIOS guidance manual (Vogl et al. 2013). A current land cover map for 2013 was generated from Landsat 8 satellite imagery (see earlier methodology outline for pre-processing and validation of the land cover map). All other maps were generated at the same 30 m resolution as the land cover map. Erosivity depends on the intensity and duration of rainfall and for this project was a single value for each watershed derived from existing literature sources. Future field work will enable more local values to be incorporated into future RIOS modeling to improve targeted investment information. Soil erodibility maps were generated from the Harmonized World Soil Database v 1.2 where soil erodibility was calculated for each soil type that was found in the watersheds from existing literature. Downslope retention index, upslope source and riparian continuity were generated in the RIOS pre-processing toolbox in ARCGIS 10.1 (ESRI 2012) and required a DEM (generated from ASTER GDEM) and a threshold flow accumulation map as well land cover, erosivity, erodibility and soil depth. Soil depth was set at 1 m for all soils as there was no local information indicating how soil depth may change. The beneficiaries map was based on population density across the two watersheds and was obtained from AfriPop which is based on 2010 population density estimates.

7.1.2 Intervention activities and associated costs

Intervention activities were riparian restoration,; reforestation and 'fanya juu' terracing and grass strips. Reforestation here involves planting trees within existing agricultural land, rather than switching land cover to forest. Within RIOS, these activities were only allowed to take place on certain land uses (Table 3). Costs are variable for SLM interventions and depend on factors such as geographic location, the steepness of slopes and available labor. In the WOCAT database, establishment costs range from US$/ha 70-740 for 'fanya juu' terraces and US$/ha 37-230 for grass strip planting (Liniger et al. 2011). Maintenance costs range between US$/ha 10-85 and 0-50 for the same (Liniger et al. 2011). Current local cost estimates are preferable but not always easily available until SLM activities have been implemented and costs defined. For this analysis, local establishment costs were estimated for riparian restoration and assisted vegetation restoration from a budget submitted for a carbon financing project in the area (Table 4). Costs for terraces and grass strips were taken from Liniger et al. (2011) and based on the highest estimate. Costs were converted to 2013 prices using a purchasing power calculation (Table 4).

7.1.3 Budget for implementing intervention activities

The budget for the initial pilot phase projects for Nyeri and Thika watersheds (Table 3; column 4) were based on proposed budgets of the local implementing partners during this period although the actual amount of money to be spent on each of these activities had not been specified. These pilot projects are one year and two years in duration for Nyeri and Thika respectively. The available budget for implementing activities over the total Water Fund period (ten years) were based on the Water Fund target budget which is expected to be US$ 20 million. For this RIOS modeling, it was assumed this budget would be divided equally amongst three priority watersheds (only two watersheds are considered in this report), and then divided equally over years within each watershed. This is likely to be an overestimate of available funds as all funding will not be spent on interventions alone. The budget allocated to each watershed was assumed to then be divided equally between all interventions within a watershed rather than allowing RIOS to allocate the area of each intervention implemented. No clumping of activities (a RIOS option which clumps activities together in the landscape) was defined so as to investigate in an unbiased way where the high priority areas were for SLM activities. Clumping of activities can be added in future iterations of the RIOS modeling.

Table 3. SLM interventions used to achieve the objectives (erosion control) of the investment fund in the Upper Tana. Interventions were specified by local partners who will be responsible for implementing the interventions. Interventions are only appropriate on certain land uses, which have been specified here.

Watershed	Intervention	Land use where intervention can be implemented	Pilot project budget (US$)	Ten year budget (US$)
Nyeri	Riparian restoration	Tea, coffee, cereals and vegetables	1882 (1 yr.)	22222.22
	Reforestation	Tea, coffee, cereals and vegetables	0	22222.22
	'Fanya juu' terracing and grass strips	Coffee, cereals and vegetables	3882 (1 yr.)	22222.22
Thika	Reforestation	Tea, coffee and vegetables	51,500 (2 yrs.)	33333.33
	'Fanya juu' terracing and grass strips	Coffee and vegetables	51,500 (2 yrs.)	33333.33

Table 4. Costs allocated to each activity.

Intervention	Intervention description	Estimated cost (US$/ha)	Estimated cost 2013 (US$/ha)
Riparian restoration and reforestation	Community mobilization, nursery management and tree planting*	475 (2007)	534 **
'Fanya juu' terraces	'Fanya juu' terraces and grass strips***	970 (2009)	1050**

* Assumes 1000 trees planted per ha. Based on a budget submitted for a biocarbon project in the area (which was later withdrawn), which included the activity of planting trees. Nursery management was included as a

cost here to cover costs of either growing or buying trees.
** Based on the purchasing power i.e. multiplying the original price by the percentage increase in the Consumer Price Index from the original year to 2013.
*** Based on cost information reviewed in Liniger et al. (2011). The upper estimate of costs were used and 'Fanya juu' terraces were chosen rather than other terrace types as these are a form of terrace most commonly used in the area.

7.2 Results

7.2.1 Nyeri watershed: Prioritization for the initial one year pilot project allocated only a very small area for SLM interventions. The majority of interventions are within the box outlined in Figure 12a and are targeted upstream from a major town in this watershed. Over the ten years of the Water Fund, riparian restoration was targeted to the north of the watershed where there are steep slopes and numerous up stream rivers which run off Mt. Kenya (Figure 13a). Reforestation and terracing was allocated throughout the watershed and found in steep areas with high soil erodibility values.

7.2.2 Thika watershed: Prioritization for the initial two year pilot project allocated the majority of the terracing and reforestation activities to the western side of the watershed where vegetable agriculture is prevalent and the terrain is steep and hilly (Figure 12b). Over the ten years of the Water Fund, prioritization allocated funds to increase the area under terracing in the western side of the watershed on almost all land with steep slopes and under vegetable cultivation (Figure 13b). Terracing was also allocated to coffee growing areas within the tea zone and on the edge of the tea zone. These areas are all up stream of major population centers and are steep and hilly. Surprisingly, terracing was not allocated to the main coffee growing area and this was because the erodibility of this area was estimated to be low using global soil data. Improved local data would most likely show that this area has much more variable soil properties than found in the global soil database used for this analysis. Reforestation would be most cost-effective in the tea zones which have steep slopes.

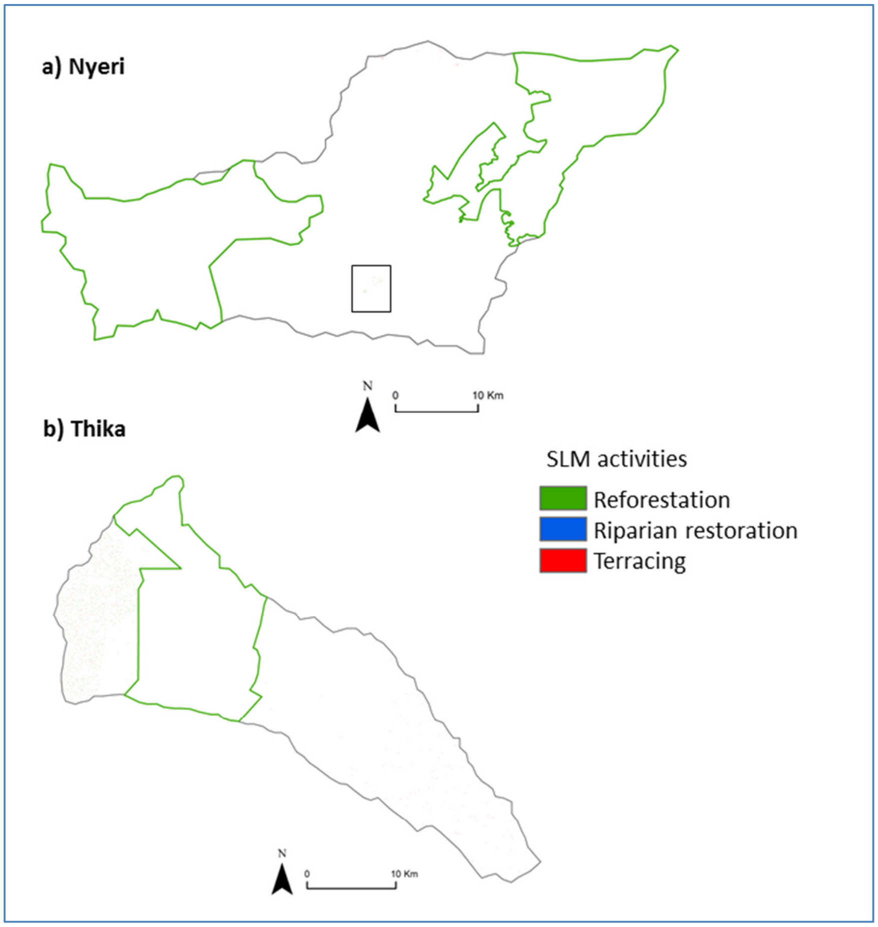


Figure12. Areas where SLM interventions should be implemented to yield the greatest returns in erosion control in (a) Nyeri and (b) Thika watersheds during the one and two year pilot projects, respectively.

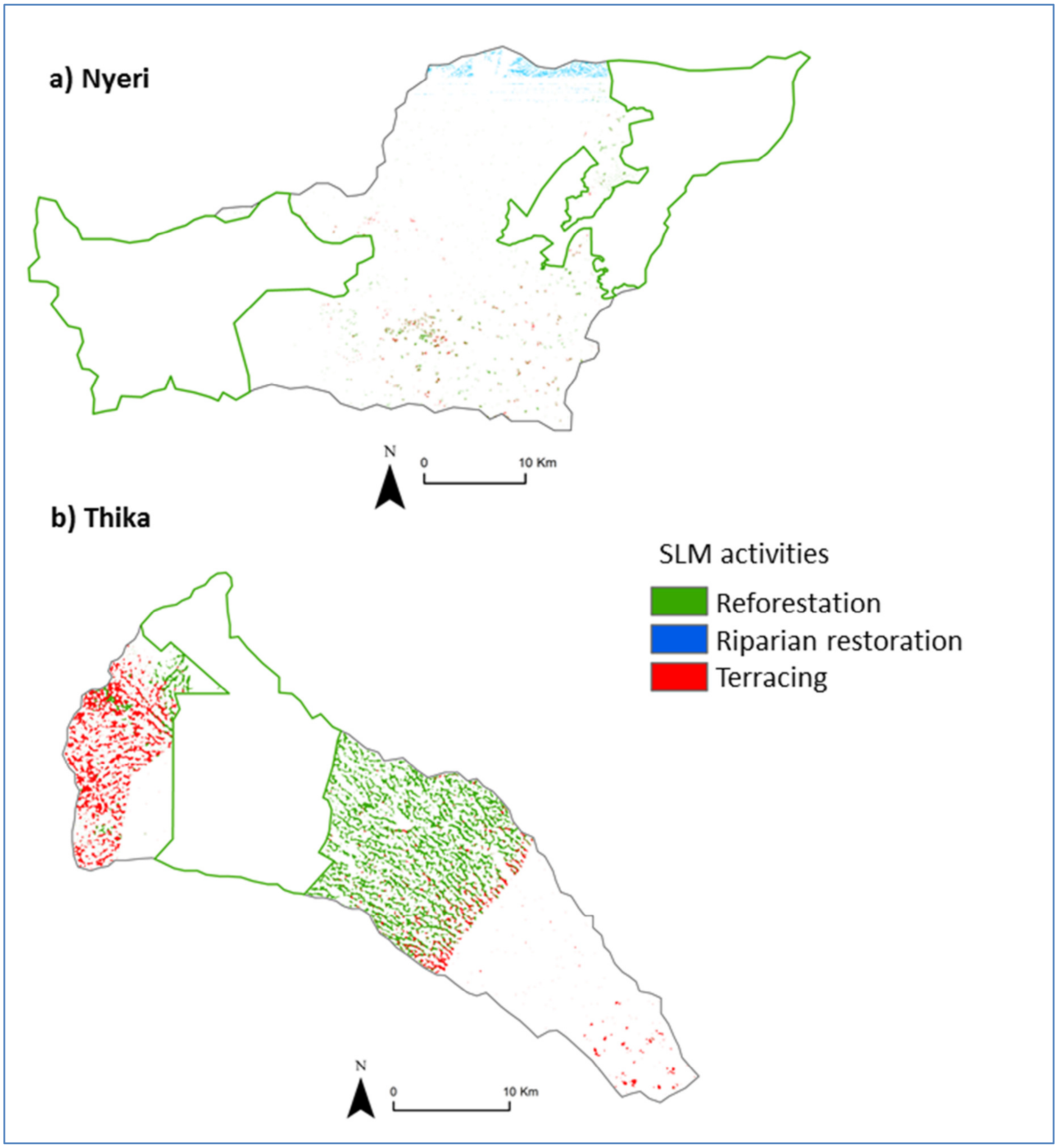


Figure 13. Areas where SLM interventions should be implemented to yield the greatest returns in erosion control in (a) Nyeri and (b) Thika watersheds during the ten year Water Fund.

7.3 Discussion

Investment portfolios are a starting point for consideration by investors and local partners implementing SLM intervention activities on the ground (Vogl et al. 2013). The process should follow numerous iterations which should be discussed amongst stakeholders. Whilst this preliminary analysis demonstrates where interventions could be most cost effective for reducing soil erosion, this is a first iteration of possible investment options. The decisions made to produce this map could be altered to produce different maps depending on stakeholder needs and preferences. Local partners may highlight areas that are unsuitable for interventions for reasons other than those included in the model. Currently, no local data has been incorporated which could improve the model. In addition, there is no allowance here for addressing erosion from quarrying, landslides or dirt roads, which have been highlighted by the SWAT modeling as an important source of soil erosion. Therefore the land management-based transitions should be considered a subset of options that can help to inform investment prioritization (Vogl et al. 2013). There three interventions considered in this analysis and were the interventions highlighted as important by local implementing partners., but there may be more intervention options to include once more baseline information is collected. The Natural Capital project is currently conducting a RIOS analysis in parallel with this study which will be combined with SWAT analysis to investigate how the investment portfolio generated by RIOS impacts soil erosion and base flow. This analysis will follow numerous iterations and stakeholder input which will be used to inform activities to be implemented by the Water Fund.

8. Partnerships, field campaigns and outreach activities

Partnerships: The Nature Conservancy is a lead partner in the development of Upper Tana- Nairobi Water Fund, a Public- Private- People partnership tool crafted by several stakeholders to provide a mechanism for long term restoration measures and conservation of the Upper Tana Watershed that millions of rural communities and Nairobi City residents depend on for water and also a major source of hydropower, a significant driver of Kenya's economy. This partnership is strategic for WLE to deliver on development challenges related to water resources and energy demands in this region and could serve as a model for other areas.

In this project TNC and CIAT collaborated to strengthen integrated research and landscape modeling tools in order to prioritize restoration and conservation work in the watershed. Other partners on this initiative include Kenya electricity and Power Generation (KENGEN), Water Resources Management Authority (WRMA), Nairobi Water Company and East African Breweries, Kenya National Federation of Agricultural Producers (KENFAP) and the Sustainable Agriculture Community Development Programs (SACDEP) and the East African Breweries.

Field campaigns: One of the outcomes of this project is a stronger and more robust hydrological monitoring system based at WRMA and partly supported by CIAT. WRMA is now carrying out periodic river gauging and sediment monitoring in critical parts of the watershed where the Water Fund, through local communities, is also implementing soil and water conservation work. A social economic baseline survey was conducted and concluded during this project period in the conservation sites and shared with partners. Field campaigns on water quality monitoring can be accessed here:
https://www.dropbox.com/s/2w31vzyqitgsdql/Upper%20Tana-%20Water%20Quality%20Monitoring%20by%20WRMA-%20CIAT-%20TNC.doc

Outreach activities: As part of activities attributed to this project, a presentation on the Water Fund model as a show case for Payment for Ecosystem Services was presented in an international forum in Cape Town hosted by UNEP in December 2013. The objective was to review different PES modalities being employed for watershed protection.
A copy of this presentation can be accessed here:
https://www.dropbox.com/s/pqkidnlfrrf8gw0/Nairobi%20Water%20Funds%20_UNEP_Cape%20Town.pdf

9. Conclusions

This study targeted 4 key groups: i) local resource users: mainly farmers, pastoralists, fishers; ii) decision and policy makers and planners at the local, regional and national levels; iii) private sector: Nairobi Water and Sewerage Company, KenGen (hydropower) and other large water users; iv) urban dwellers through adequate power and clean water supply for the people in Nairobi. The involvement of local actors will guarantee a follow up after the project cycle while the inclusion of development actors and private sector will allow translation of research results into concrete actions.

As indicated in this report, the activities reported towards each of the three project objectives (See pg.3) provided a critical jumpstart towards reaching longer term goals and are helping to build a business case for sustainable management of water and land resources in this watershed. Some of the unfinished components of the project are still on-going given the big spatial coverage of the study area and are being conducted through joint efforts with CIAT's WLE POWB 2014. Use of the tested tools and frameworks on other WLE-related sites will also help build a community of practice and contribute to scaling up of project results across different agro-ecological zones.

This research is needed because restoration and better management of degraded ecosystems can reinstate the resource base of communities who live within these ecosystems and enhance the flow of environmental services available to various beneficiaries. While the need for conservation and restoration of this river basin's ecosystems is clear to the stakeholders and actors involved, the best way to meet that need is when scientific research provides viable and practical options through improved evidence-based recommendations and well informed decisions relating to land, water and ecosystems.

This research will contribute to the core of WLE's intermediate development outcomes through sustainable increases in land, water and energy productivity in both rainfed and irrigated agroecosystems as well as increased resilience of communities through enhanced ecosystem services in agricultural landscapes. The proposed work will lead to solutions and impacts beyond the current phase because sustainable changes in these landscapes are more long-term and take concerted efforts at various levels and sectors in society that strategically combine a bottom-up and top-down approach. The strengthened partnerships between WLE scientists doing research for development with TNC and the private sector are testament to this.

10. Acknowledgement

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