The business case for small hydropower schemes to invest in catchment management: two case studies in Kenya and Tanzania

December 2018

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FutureWater Report 183

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Summary

This study assessed the impacts of various investment portfolios for catchment management activities on the cost-benefits of small hydropower schemes, in two case study catchments in Kenya and Tanzania, and analyzes the return-on-investment for the hydropower developers. Catchment degradation trends, climate change impacts and socio-economic changes increasing competing water use were considered.

For each of the two catchments, satellite imagery and field observations were combined to perform a land degradation assessment and to identify trends. Secondly, baseline hydrological conditions were assessed using a hydrological simulation model. Future changes in hydrology and hydropower generation were evaluated by running the biophysical model for a Business-as-Usual scenario, accounting for land degradation trends, changes in water use, and climate change.

Subsequently, the impacts of three catchment investment portfolios (low, medium, high) containing different catchment activities were quantified with respect to the BaU scenario. Benefits and costs were analysed for the hydropower developers to evaluate whether it makes sense for them to invest in improved catchment activities. For one of the catchments this is clearly the case (Kiwira, Tanzania).

The analysis shows that the impacts of climate change on revenue from hydropower are in the same order of magnitude as the other negative anthropogenic factors: increased domestic water use demand in the catchment and land degradation due to poor conservation of natural areas and poor agricultural practices.

Overall, the return-on-investment analysis shows that to ensure hydropower sustainability, it is needed to (i) implement long-term viable tariffs; (ii) accept long-term investment horizons, and (iii) accept sub-commercial discount rates for investments in the environment.

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1 Introduction

1.1 Background

When hydropower facilities are developed and operated, the revenue stemming from sale of electricity rarely benefits the communities living within the catchment, nor does it support the protection of the catchment in which the hydropower project is located. This potentially leads to unsustainable management of resources and increases the risks faced by the catchment communities, the facility and its investors.

In Kenya, a larger Upper Tana - Nairobi Water Fund Programme was launched in 2017 with support from the Nature Conservancy (TNC). It recognizes that the water supply of the Nairobi area largely depends on sources in the Upper Tana Catchment (Hunink and Droogers, 2015). The Fund employs a payment for ecosystems services mechanism to facilitate investments in the conservation of upstream catchments to regulate water flows and trap sediment (Vogl et al., 2016).

The GIZ-implemented International Water Stewardship Programme (IWaSP) is funded by the Governments of Germany and the UK. The current study is supported by IWaSP and builds on the business case of the Upper Tana – Nairobi Water Fund. It applies a very similar business case analysis methodology to small hydropower investments in a catchment in Kenya and one in Tanzania. Based on the outcomes of this study, it is envisioned that IWaSP could reframe small hydropower project (SHPP) developments as an important vector for sustainable development with an explicit focus on resolving embedded issues of social and environmental equity. Bringing ecosystem services to the center and creating mechanisms to transfer the benefits will support long term socio-economic and environmental development.

This report describes the methodology, results, and implications of the business case analysis for the two case study areas: the Nyamindi River Catchment (part of the Tana River Basin in the Mount Kenya area), Kenya and the Kiwira River Catchment (in the Lake Nyasa/Lake Malawi Basin), Tanzania.

1.2 Objective

The main objective is to assess whether there is a business case for small hydropower developers to invest in Sustainable Land Management (SLM) in the catchment: providing them benefits from having more reliable flow conditions.

To meet this objective, the following research questions are answered:

1. What are the costs of catchment degradation to hydropower operations during a 20-year concession period?
2. Under which conditions does it make economic sense to hydropower developers/operators to invest in catchment management?
3. What are the expected returns on investment in catchment management for hydropower developers/operators during a 20-year concession period?

The report presents in Chapter 2: Data and methods, Chapter 3: Results, and Chapter 4: Conclusions.

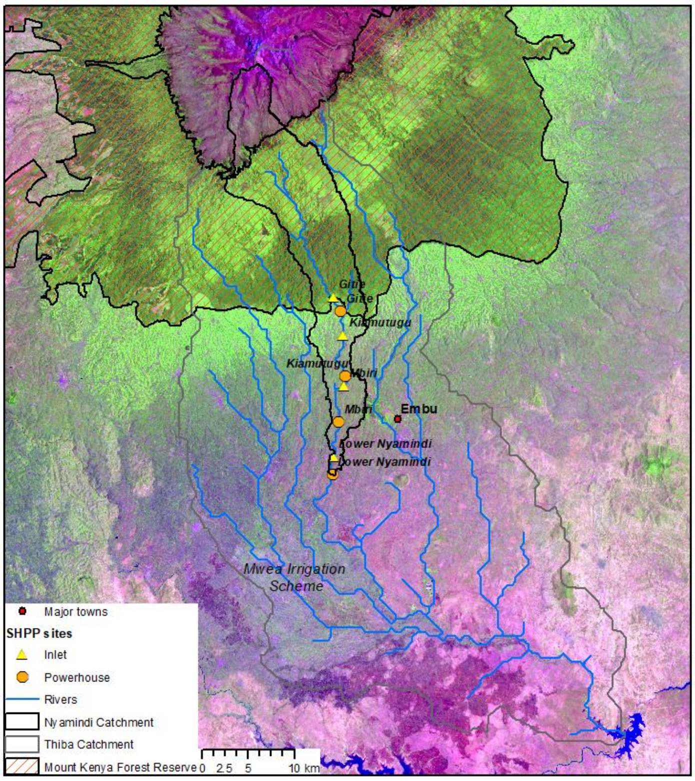
2 Data and methods

2.1 Study areas

2.1.1 Nyamindi River Catchment, Kenya

The Nyamindi River Catchment is located in Kirinyaga County, central Kenya, west of the town of Embu. The Nyamindi River originates from Mount Kenya, flows southward and drains into Thiba River. Figure 1 shows the location of Nyamindi River within the Thiba Catchment, to the south of Mount Kenya. The upper part of the Nyamindi Catchment is largely comprised of the montane forests of the Mount Kenya National Park, bordered to the south by extensive stretches of agricultural land occupied by smallholder farms (see Appendix I).

Despite their protected status, the forests of Mount Kenya continue to be affected by logging. In addition, an increasing number of people living around the periphery of the forest make daily incursions up the mountain to graze livestock, and collect fire wood and non-timber forest products (UNESCO[1]). In the entire Thiba Catchment, forest cover has decreased by 18% between 1984 and 2014 while the extent of area under cultivation increased with over 9% in the same period (M. Kasuni, 2017). Additional points for water abstraction were constructed recently within the protected forests of the Nyamindi Catchment, although these provide piped water supply to communities downstream and reportedly have limited impact on surrounding areas.



[1] https://whc.unesco.org/en/list/800/

Figure 1 False-color 2017 Landsat composite (5-4-3) with Thiba Catchment boundaries, Nyamindi hydropower development sites and other locations of interest indicated. Landsat data was downloaded from the Global Forest Change dataset[1].

Two hydropower developers are currently active in the Nyamindi River Catchment, constructing a total of 4 SHPPs (Table 1). Both developers will own and operate the projects for a 20-year concession period:

- responsAbility, a Swiss financial intermediary, develops the Upper Nyamindi hydropower cascade in partnership with Eco Power, a Sri Lankan SHPP developer and EPC contractor. A local project proponent holds a minority share in the projects. The greater Nyamindi project consists of three run-of-river grid connected small hydropower plants located along the river between the forest and the Embu-Kutus road. The three run-off the river projects are named Gitie, Kiamutugu, Mbiri. Each of the three projects will have an installed capacity of approximately 6MW. The projects follow a conventional run-of-river layout, including intake, conveyance channel, forebay, penstock pipes and powerhouse with tailrace. The sub-catchment and intake of Gitie, the most upstream project, is situated in a largely undisturbed forested area of the Mount Kenya Forest Reserve. All other installations are on agricultural land, occupied by smallholder farms.
- Downstream, the Kenya Tea Development Agency, through its subsidiary KTDA Power, constructs the Lower Nyamindi SHPP. The scheme is now near completion. It follows a run-of-river layout and is rated at 1.8MW. All installations are on agricultural land, occupied by smallholder farms.

Table 1 Small hydropower projects in Nyamindi River Catchment and their key properties.

Name	*Firm*	*Intake*		*Powerhouse*		*Installed capacity*
		Latitude	**Longitude**	**Latitude**	**Longitude**	**MW**
Gitie	responsAbility	-0.3997222	37.38717	-0.4140278	37.39447	6
Kiamutugu	responsAbility	-0.4368056	37.39842	-0.4770611	37.39894	6
Mbiri	responsAbility	-0.4867222	37.39806	-0.5221778	37.39277	6
Lower Nyamindi	KTDA Power	-0.5548389	37.38791	-0.5730944	37.38688	1.8

2.1.2 Kiwira River Catchment, Tanzania

The Kiwira River Catchment is in the Mbeya Region of southwestern Tanzania. The catchment has a size of approximately 1,900 km^2 and forms part of the Lake Nyasa Basin. Its main stream, Kiwira River, rises in the Poroto Mountains southeast of the town of Mbeya and receives several streams originating on the slopes of Mount Rungwe. The river flows in a southerly direction, ultimately draining into the northern end of Lake Nyasa (also known as Lake Malawi).

The upper catchment covers several evergreen, high forest ecosystems (Appendix I), receiving abundant rainfall. Catchment-average rainfall is reported at 1,866 mm (LNBWB, 2015). The Mount Rungwe Nature Forest Reserve is a key area for conservation of residual tropical montane forest as well as endemic and endangered biodiversity. North of the reserve, the Kiwira Forest Plantation (2,784 ha) is managed by the Tanzania Forestry Services Agency and is largely covered by pine forest (TFSA, 2013). Figure 2 presents a false-color Landsat

[1] https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html

composite of the year 2017 for the full catchment and its surroundings, with natural forests indicated in bright green.

As a consequence of high rainfall and fertile soils, a substantial part of the Kiwira Catchment is comprised of agricultural land, with 25% of the upper catchment under cultivation[1] (see Appendix I). Important crops include potatoes and maize, which are sold commercially. Plot sizes are typically far below 1 ha (Mwanukuzi, 2011). With a population density of 124 persons / km², the Kiwira Catchment supports a relatively large number of inhabitants.

Due to occurrence of heavy rains and the presence of friable volcanic soils and steep slopes, the land is vulnerable to degradation. Over the past decades, human actions have exacerbated catchment degradation. Replacement of pyrethrum farms with potato and maize farms, replacement of natural vegetation with eucalyptus and pine trees, and removal of terraces and contour bunds on sloping lands are some of the main land management changes observed (Mwanukuzi, 2011). These have led to several forms of catchment degradation, including soil fertility loss, gully erosion, soil loss, biodiversity loss and drying up of river sources. Advancing gully erosion due to population growth and poor land management is threatening the town of Igoma, the largest settlement in the upper Kiwira Catchment (Sokoni, 2014).

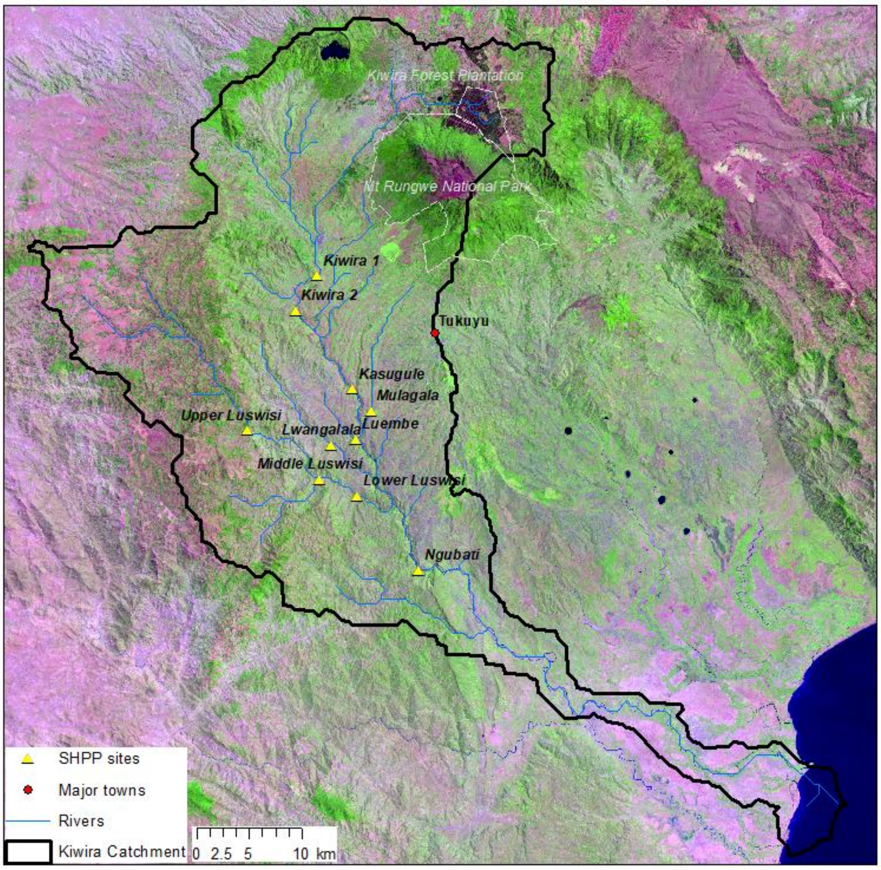


Figure 2 False-color 2017 Landsat composite (5-4-3) with Kiwira Catchment boundaries, hydropower development sites and other locations of interest indicated. The Landsat data was downloaded from the Global Forest Change dataset[2].

[1] Copernicus data.
[2] *https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html*

Frontier Energy, a Danish financial intermediary, together with Tanzanian joint venture partner Mkonge Energy Systems Ltd. is developing nine hydropower projects in the Kiwira Catchment. Four of these projects are on the main river, while the other projects are on its tributaries Mulangala, Luembe, Lwangalala and Luswisi (two sites). The total generation potential is about 43 MW, with sites ranging from 1.6 to 6.9 MW (Table 2). All projects follow a conventional run-of-river layout, including intake, conveyance channel, forebay, penstock pipes and powerhouse with tailrace. Frontier and Mkonge will own and operate the assets during a 25-year concession period, under a joint venture named Kiwira Energy Ltd.

An additional SHPP is being developed by Bwelui Ltd, a company founded by local environmental NGO KMIM, Ileje District Council and Ensol Tanzania Ltd, a Tanzanian company developing renewable energy projects. This project is located on the Upper Luswisi River, a tributary of the Kiwira. The project follows a conventional run-of-river layout, including intake, conveyance channel, forebay, penstock pipes and powerhouse with tailrace, and makes use of a waterfall located above the village of Bwenda (Bwelui Company Ltd, 2017). Bwelui has agreed a 25-year concession and power purchase agreement with TANESCO, the state utility.

Table 2 Small hydropower projects in Kiwira River Catchment and their key properties.

Name	***Developer***	***Intake***		***Installed capacity***	***Assumed head***
		Latitude	**Longitude**	**MW**	**m**
Kiwira 1	Kiwira Energy Ltd	-9.2	33.53832	4.3	30.4
Kiwira 2	Kiwira Energy Ltd	-9.229586	33.51939	5	30.7
Kasugusule	Kiwira Energy Ltd	-9.297183	33.56976	6.1	32.1
Mulagala	Kiwira Energy Ltd	-9.316608	33.58491	3.5	167
Luembe	Kiwira Energy Ltd	-9.340292	33.57083	1.6	95
Lwangalala	Kiwira Energy Ltd	-9.345086	33.55071	3.2	164
Upper Luswisi	Bwelui Ltd	-9.332769	33.47814	4.7	140
Middle Luswisi	Kiwira Energy Ltd	-9.374736	33.54044	6.5	170
Lower Luswisi	Kiwira Energy Ltd	-9.388717	33.57291	6.1	156
Ngubati	Kiwira Energy Ltd	-9.452853	33.62566	6.9	23.5

2.2 Approach

The approach for this assessment is based on the Upper Tana business case study (Hunink and Droogers, 2015). For each of the two catchments, a variety of satellite imagery, remote sensing-derived datasets and other GIS data such as land cover maps and field observations were combined to perform a spatial land use assessment and identify trends. Secondly, baseline hydrological conditions were assessed using a biophysical simulation model. Any future changes in hydrology and hydropower generation were evaluated by running the biophysical model for a Business-as-Usual (BaU) scenario, accounting for land degradation trends, changes in water use, and climate change. Subsequently, the impacts of three catchment investment portfolios (low, medium, high) containing different SLM activities were quantified with respect to the BaU scenario. To answer the key questions posed in paragraph 1.2, for each investment scenario these impacts were monetized in terms of revenue to the hydropower operator and evaluated against investment costs to investigate the viability of a business case.

The different steps are discussed below in more detail.

2.2.1 *Spatial land use assessment and trend analysis*

An analysis was conducted based on existing land-cover maps, updated with high-resolution satellite imagery to assess the land cover classes and structure, its function, and changes over the last 20 years. The analysis improved on the previous Upper Tana business case by using imagery of the last 20-years of the NASA Landsat platforms (30m) and ESA Sentinel satellites (10m), and by using the latest remote sensing technology and algorithms such as offered by Google Earth Engine. The Normalized Difference Vegetation Index (NDVI), as a key proxy of fast runoff generation and susceptibility to erosion, was analysed through time to identify land degradation trends in the two catchments. Deforestation trends were evaluated using the state-of-the-art Hansen dataset available from the Global Forest Change Explorer. Additional datasets of human activity potentially influencing land degradation include the development of the road network (Open Streetmap), the location of newly constructed water abstraction points in Nyamindi, and erosion and deforestation hotspots observed in the field for the Luswisi subcatchment in Tanzania (LNBWB, 2018).

2.2.2 *Biophysical modelling: baseline and Business-as-Usual*

The biophysical modelling component serves to dynamically simulate the catchment processes impacting hydropower generation and SHPP lifespan. A physically-based spatial hydrological model with satisfactory performance under baseline conditions allows for the evaluation of likely developments in the catchments over the next decades, as well as the projected impact of SLM activities on downstream SHPPs.

The Spatial Processes in HYdrology model (SPHY) was selected as the most appropriate tool to perform this analysis. Key strengths of SPHY are the physically-based approach, allowing for long-term simulations on a daily timestep, its grid-based nature allowing for easy incorporation of remote sensing information in data-scarce areas and its successful application in previous similar studies. A detailed description of the model and its concepts is provided in Appendix II.1. SPHY was set up for the period 1998 – 2017 to analyze baseline conditions in the Nyamindi and Kiwira catchments. Calibration of the model was performed as described in Appendix II.2. Datasets used in the model are presented in Table 3.

Table 3 Overview of datasets that were used.

Description	***Source***	***Resolution***	***Purpose***
Elevation	SRTM	30 m	Model input
Daily rainfall	CHIRPS Station data	5 km -	Model input
Temperature	NOAA Global Summary Of the Day (GSOD)		
Soil hydraulic properties	HiHydroSoil	250 m	Model input
Land use / land cover	Copernicus	100 m	Model input
NDVI	Landsat Sentinel	30 m 10 m	Model input
Road network	Open Streetmap	-	Scenario development
Climate scenarios	NASA NEX		Scenario development

Forest cover change	Global Forest Change Explorer	30 m	Scenario development
Protected areas	WDPA	-	
Streamflow data (Kiwira)	Lake Nyasa Basin Water Board	-	Model calibration
Actual evapotranspiration	SSEBop	1 km	Model validation

As the impact of SLM activities should be evaluated over the next decades, it should be assessed against the Business-as-Usual conditions expected over this period. Land degradation, water use and climate were identified as the three main factors that are likely to change over the next decades. The land degradation trends were implemented in SPHY based on the NDVI trends identified in the spatial land use assessment described in Paragraph 2.2.1 and considering the deforestation trends as were observed in the previously mentioned Hansen dataset. Changes in water use and climate were incorporated based on population growth projections and climate scenarios, as elaborated in Appendix III.

An overview of all main steps in the biophysical modelling is provided in Figure 3.

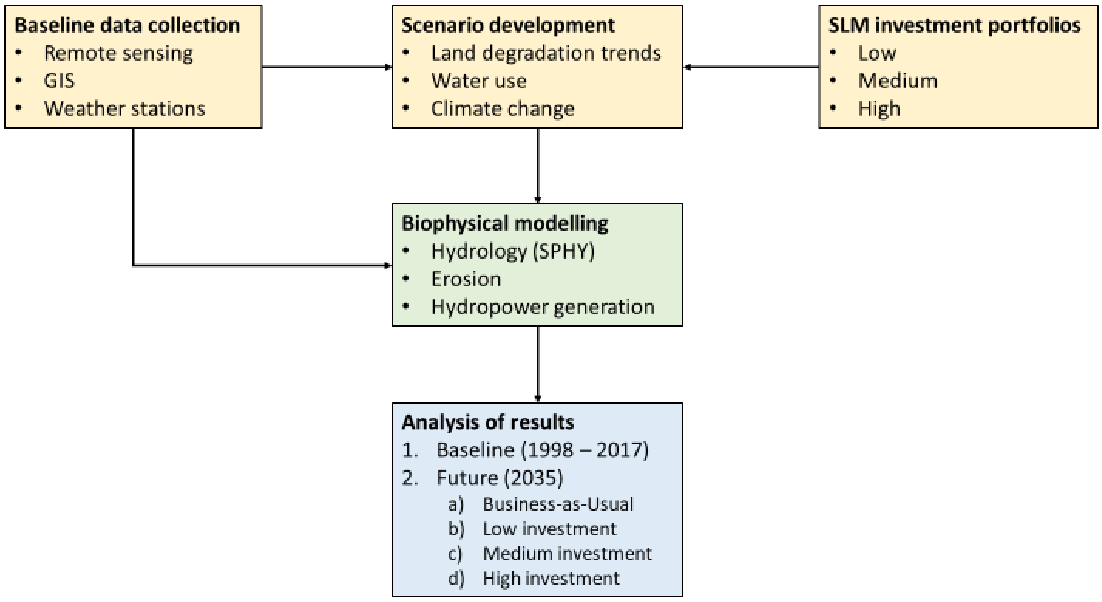


Figure 3. Outline of the biophysical modelling component of the study.

2.2.3 Sustainable land management scenarios

Three SLM investment portfolios were defined and spatially targeted in the catchment. The SLM activities that were included (similar as in the Upper Tana business case study):

- Riparian management;
- Forest conservation;
- Terracing;
- Other agricultural SLM measures (mulching, conservation tillage, vegetative strips, etc.); and
- Road erosion mitigation.

The three portfolios were based on different intensity levels of implementation and associated costs (low, medium, high). Table 4 shows the total cost for each of the catchments and investment levels. More details are given in Appendix IV.

Table 4. Total investment costs (million USD) for the low, medium and high SLM scenarios.

Area	**Investment portfolio SLM activities**		
	Low	***Medium***	***High***
Nyamindi	0.6	1.2	1.9
Kiwira	6	12	19

The cost of the high investment scenario is approximately 3% of the expected 10-year revenue from power generation for the Nyamindi Catchment, and 6% for the Kiwira Catchment.

The full specifications of these investment portfolios and their parameterisation in the model are provided in Appendix IV.

2.2.4 Financial analysis

The key question this analysis seeks to answer is whether the benefits from sustainable land management activities in catchments with small hydropower projects are likely to outweigh the costs associated with them. A financial analysis is performed to assess whether the investment is financially viable. The benefits considered in this analysis are limited to those that correspond to the hydropower developers. Obviously, there are more beneficiaries from sustainable land management activities in the catchments: forest-related stakeholders and farmers, but also possibly other downstream water users, as for example water supply utilities. These benefits are not considered in this study: the question is limited to whether there is a business case for the hydropower developers.

For assessing the benefits to hydropower, the following main assumptions are done:

- For Kenya and Tanzania, the respective regulator-approved tariffs were used for the analysis. Besides, a higher feed-in tariff was included based on the GET FiT Initiative, to assess how these subsidized tariffs improve the returns;
- Annual lost income related to hydro-abrasive erosion and maintenance costs and repair of turbines are assumed to be 2% of total project investment costs. Typically, total annual O&M costs of small hydropower are in the order of 5% of total investment costs. These maintenance costs are assumed to be linear with the mean sediment loads that were assessed using the hydrological model. For the Kenya case, investment costs were estimated based on a typical figure for small hydropower investments: 4 million USD/MW installed capacity.

For assessing the costs of the SLM investment scenarios, the principal assumptions are:

- The annual costs of maintenance of the SLM activities are equal to 5% of the investment costs of the same activities;
- The investment costs of the SLM activities were based on a unit cost per hectare of implementation of a specific SLM activity. The table per activity can be found in Appendix IV;
- It was assumed that the total investment costs are disbursed over a period of 10 years.

The financial analysis presented in the report consists of:

- A comparison of revenue from power generation in the baseline period versus the BaU scenario;
- A return-on-investment analysis based on Net Present Value to account for the time value of money;
- A sensitivity analysis to assess how the financial viability depends on a number of assumptions: time horizon, electricity tariffs and discount rates.

These three parts of the financial analysis allow responding the three key questions of this study as were listed in the objectives.

3 Results

3.1 Land use and land degradation trends

3.1.1 Nyamindi

The Global Forest Change dataset was used to analyze forest cover loss in the Nyamindi Catchment and the greater Mount Kenya Forest Reserve (Hansen et al., 2013). Figure 4 shows, in red, the areas where a change from a forest to a non-forest state was observed in the period 2000 - 2017. Deforestation is particularly located along the edges of the reserve, illustrating the encroachment of natural forests. In total, 5,100 hectares of forest were lost in 2000 – 2017, or a total of 2.4% of the total protected surface area of 212.000ha.

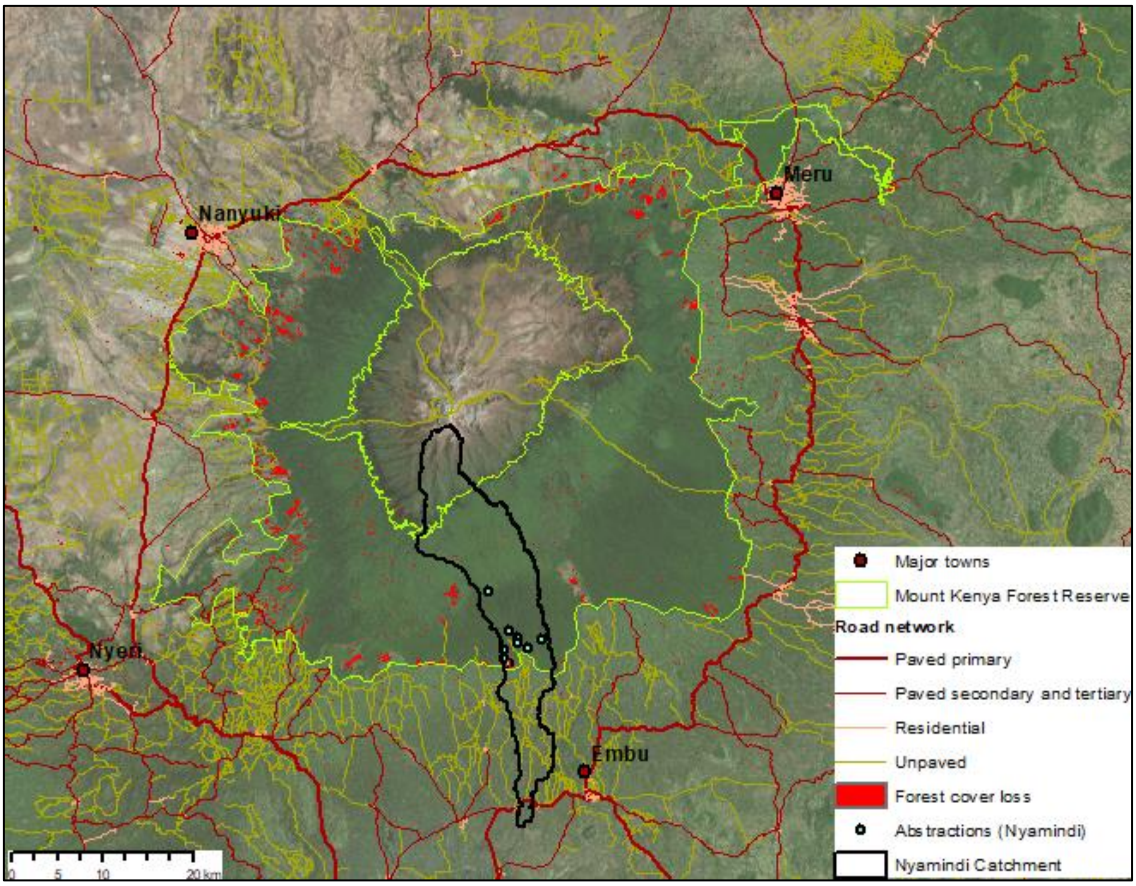


Figure 4. Map of deforestation and other human activity around Mount Kenya and in the Nyamindi Catchment. Forest cover loss (in red) is valid for 2000 – 2017 and is extracted from the Global Forest Change Explorer dataset (Hansen et al., 2013).

Destruction of natural forests leads to decreasing canopy cover, which is closely correlated to the Normalized Difference Vegetation Index (NDVI). The NDVI is a commonly used satellite-derived indicator of vegetation health and greenness. High-resolution imagery of satellites Landsat 5, Landsat 7 and Landsat 8 (30m) was used to extract a time series of average NDVI of the Mount Kenya forests. Figure 5 shows the value of annual area-averaged NDVI over the period 2003 – 2016, for which a good temporal coverage of satellite images is present in the archive of the Google Earth Engine platform. A long-term declining trend can be observed.

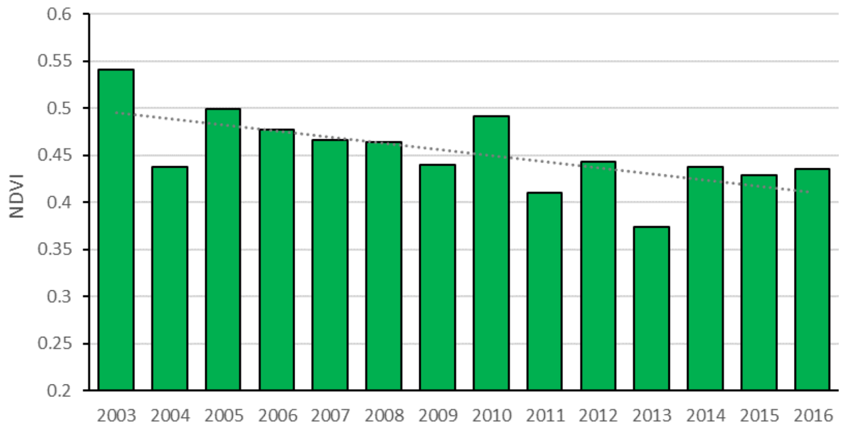


Figure 5. Timeseries of annually averaged satellite-derived NDVI (Landsat 5, 7, and 8) for the period 2003 – 2016, averaged for Mount Kenya National Park.

3.1.2 Kiwira

Excluding forest cover dynamics of the Kiwira Plantation area, which already existed before the year 2000, a total of 5,900 ha of forest loss is visible in Landsat data for the 2000 – 2017 period. This amounts to a portion of 4.7 % of the total forested area in the Kiwira Catchment of 125,500 hectares. One of the most affected areas is the Upper Luswisi Subcatchment, in the west of the Kiwira Catchment, as indicated by both the satellite data and field-observed degradation hotspots (Figure 6). Google Earth imagery clearly shows the disappearance of substantial patches of forest in this area (Figure 7). Other notable patches of deforestation are found around the Mount Rungwe Reserve, although forest cover loss is observed throughout the catchment.

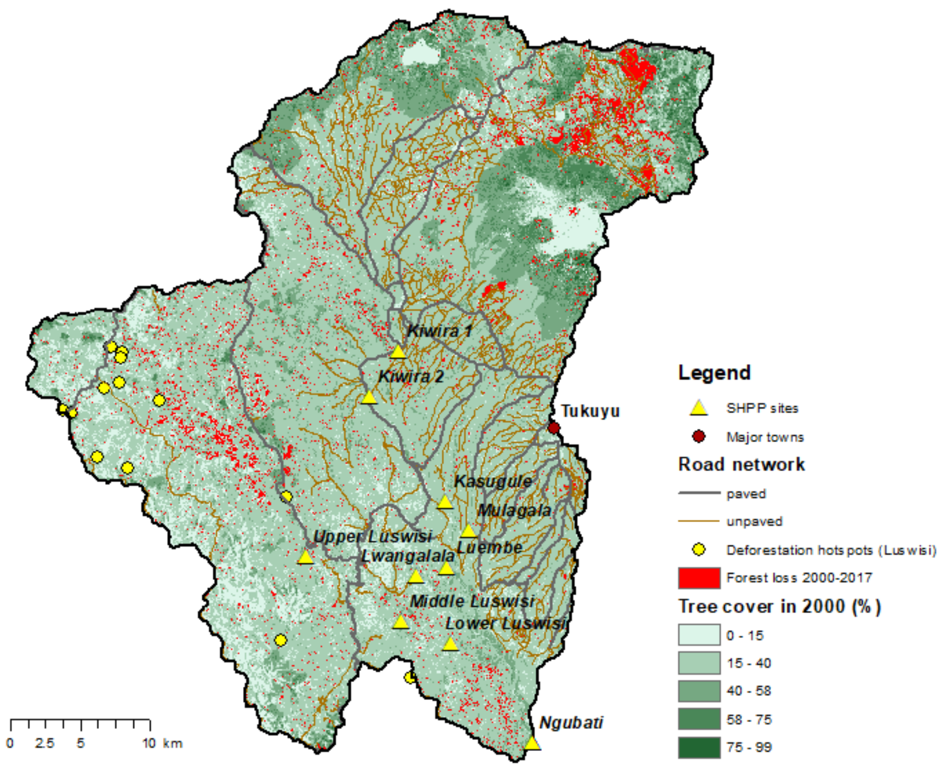


Figure 6. Map of tree cover in 2000, catchment degradation and main human activity in Kiwira River Catchment.

Figure 7. Example area of deforestation and road construction in the Upper Luswisi Subcatchment, Kiwira Catchment. Left July 2004, right October 2017 (Google Earth imagery). The yellow dot, inserted for reference, is located at 9°15'49.55"S, 33°28'7.42"E.

Similar to what was observed in the Mount Kenya Reserve, the high-resolution imagery shows that deforestation has also impacted canopy cover in the Kiwira Catchment.

The NDVI trends for the entire Kiwira Catchment were found not to be significant due to the high heterogeneity in land use types and the large catchment size (see Appendix V). However, as shown, the high-resolution satellite dataset on deforestation shows a clear negative trend. It can be expected that if this trend continues over the next 20 years, this will reflect in NDVI values. For the BaU we thus assumed a reduction in NDVI similar to the Nyamindi Catchment.

3.2 Impacts on hydrology and hydropower

This section presents outcomes of the biophysical modelling for the baseline, BaU and the three SLM investment scenarios.

3.2.1 Nyamindi

Figure 8 shows the mean annual surface runoff as simulated by the hydrological model, based on daily outputs over a 20-year period. The model distinguishes between fast runoff and baseflow, the latter constitutes the main component of dry season streamflow. The maps show the direct (fast) component of runoff generated by rainfall for the baseline scenario (left), the difference between baseline past and BaU future without SLM investments (middle), and the difference between BaU and high investment future (right).

For the Nyamindi Catchment, climate projections show increased rainfall (particularly during the wet season) and only a minor increase in temperature. Therefore, in spite of slightly higher evapotranspiration rates, this ultimately translates in higher runoff and thus streamflow. Lower canopy cover in the border zone of the Mount Kenya Reserve under BaU conditions cause evapotranspiration rates to go down, and generate a significant runoff increase. Whether this runoff increase finally benefits hydropower generation depends on the regime: if runoff peaks increase above the maximum turbine flow, this will not lead to additional power generation.

SLM activities in the investment scenarios are concentrated in the border zone of the Reserve and the agricultural lands in the southern half of the catchment (see Figure 21 in Appendix IV), and cause reductions in fast runoff as illustrated in the right panel of Figure 8. With SLM activities leading to a healthier soil profile, most of this "freed up" fast runoff infiltrates and percolates to the groundwater under the high investment scenario, thus contributing to dry season river flows.

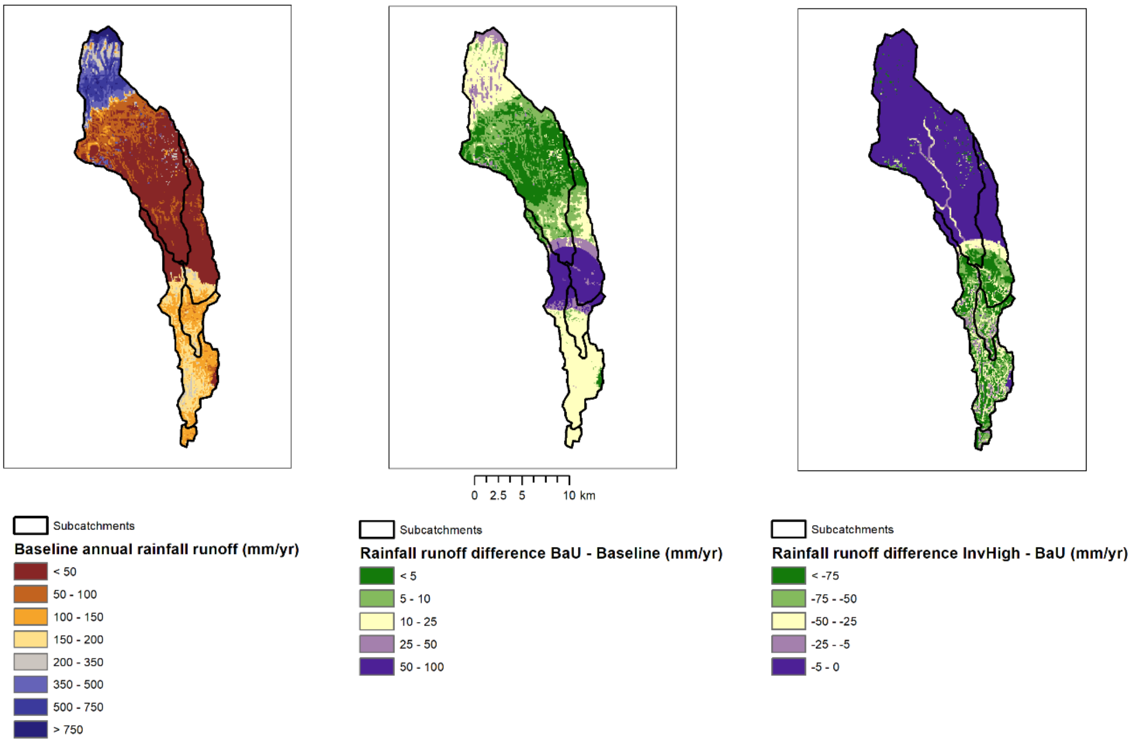


Figure 8. Baseline annual average fast runoff in the Nyamindi Catchment, and projected changes under the BaU and high SLM investment scenarios.

How the flow regime, and peak flows versus low flows will change in the future and altered by the combination of land degradation and climate change is shown visually in Figure 9. The so-called flow duration curve plots the percentage of time a certain flow is exceeded, and is a commonly used tool in hydropower feasibility and design studies. The curve shows that both low as well as high flows increase in the BaU scenario compared to the baseline. For the Nyamindi Catchment, the high investment scenario is relatively similar to the BaU, however peak and high flows are slightly lower than BaU. Low flows increase slightly but this can hardly be seen in this figure.

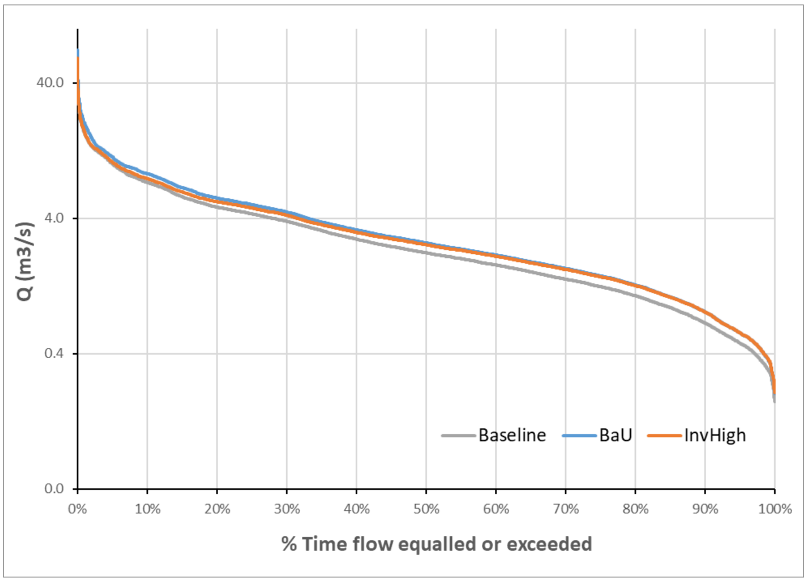


Figure 9. Flow duration curves for the Lower Nyamindi site in Nyamindi Catchment, under baseline, BaU and the high SLM investment scenario.

Figure 10 shows the mean annual power generation for the four planned facilities, for the BaU and the three investment scenarios. As can be seen, generated power increases considerably for the BaU compared to the baseline scenario due to increased streamflows. Power generation further increases under the investment scenarios, thanks to the slight redistribution of wet season flow to dry season flow illustrated by the flow duration curve.

Table 5 shows the total power generation and the difference with the BaU scenario. Under the high investment scenario, electricity generation increases with almost 2%.

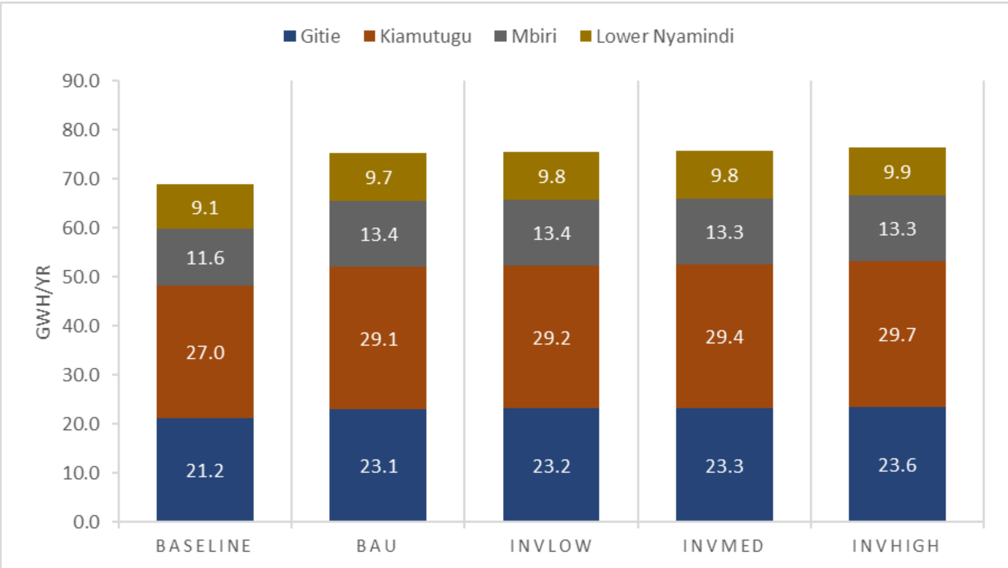


Figure 10. Hydropower generation in the Nyamindi Catchment under the baseline, BaU and different SLM investment scenarios.

Table 5. Total hydropower generation (GWh/yr) for all scenarios and difference with BaU for Nyamindi Catchment

	Baseline	BaU	InvLow	InvMed	InvHigh
Total power generation	71.9	78.5	78.8	79.1	79.9
Difference with BaU			+0.2	+0.6	+1.3
Relative diff. with BaU			+0.3%	+0.7%	+1.7%

3.2.2 Kiwira

Figure 10 shows the maps of the mean annual fast runoff based on daily outputs over the 20-year period, for the baseline scenario (left) and the difference between the baseline past and the BaU future (middle), and the difference between BaU and the high investment scenario future (right).

The figure clearly shows an increase of fast runoff across the catchment, particularly due to the combination of climate change and the loss of canopy cover, infiltration of water into the root zone as well as evapotranspiration. It should be noted that the overall annual runoff (fast + slow) increases to a lesser extent, as part of the fast runoff increase can be attributed to a redistribution of dry season runoff to the wet season. This effect is compensated by the high SLM investment portfolio, as presented in the right figure.

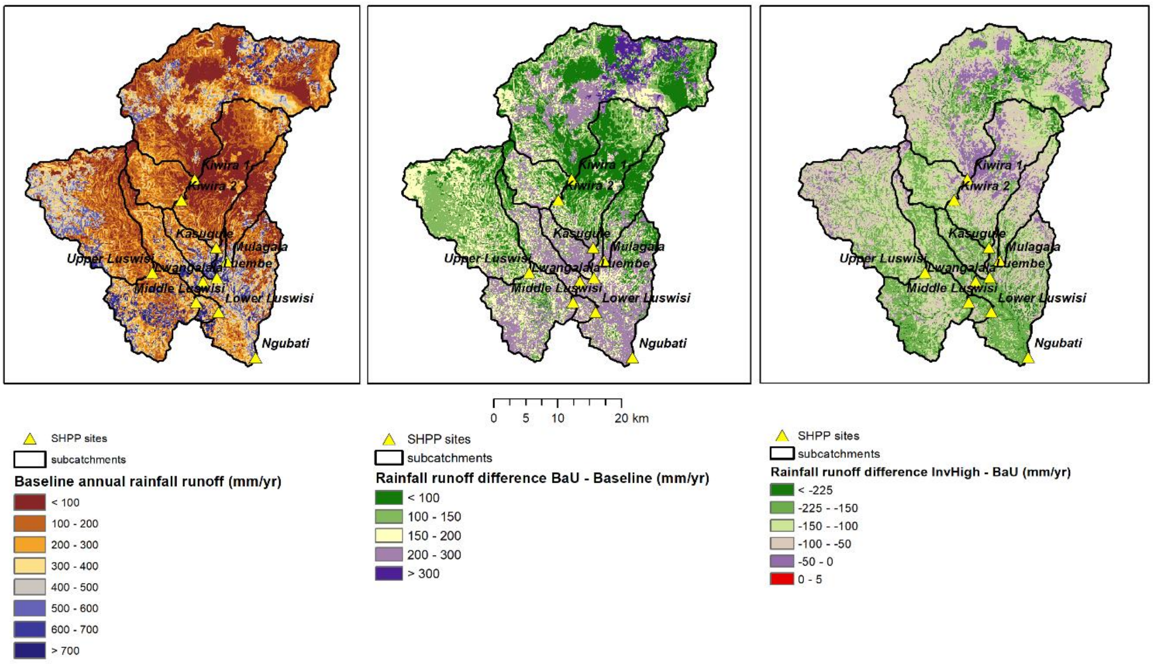


Figure 10. Baseline annual average fast runoff from rainfall in the Kiwira Catchment, and projected changes under the BaU and high SLM investment scenarios.

Figure 11 shows the flow duration curve for one of the SHP sites. The curve shows that peak flows increase in the BaU and low flows decrease; in other words: a less favorable flow regime for hydropower. The InvHigh compensates this negative change and thus leads to higher electricity generation than BaU and the baseline, as shown in Figure 12.

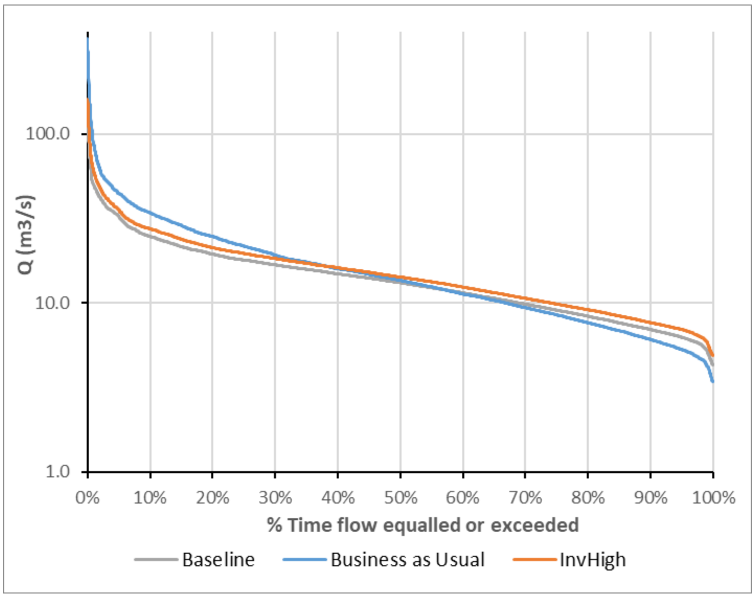


Figure 11. Flow duration curves for the Kasugusule site in Kiwira Catchment, under baseline, BaU and the high SLM investment scenario.

Figure 12 shows the mean annual power generation for all planned facilities, for the baseline, BaU and the three investment scenarios. As can be seen, generated power reduces considerably for the BaU compared to the baseline scenario due to the combined effect of land degradation and climate change. However, power generation increases considerably under the investment scenarios, to even higher levels than in the baseline.

Table 6 shows the total power generation and the difference with the BaU scenario. Under the investment scenarios, electricity generation increases between 4% and 8% compared to BaU.

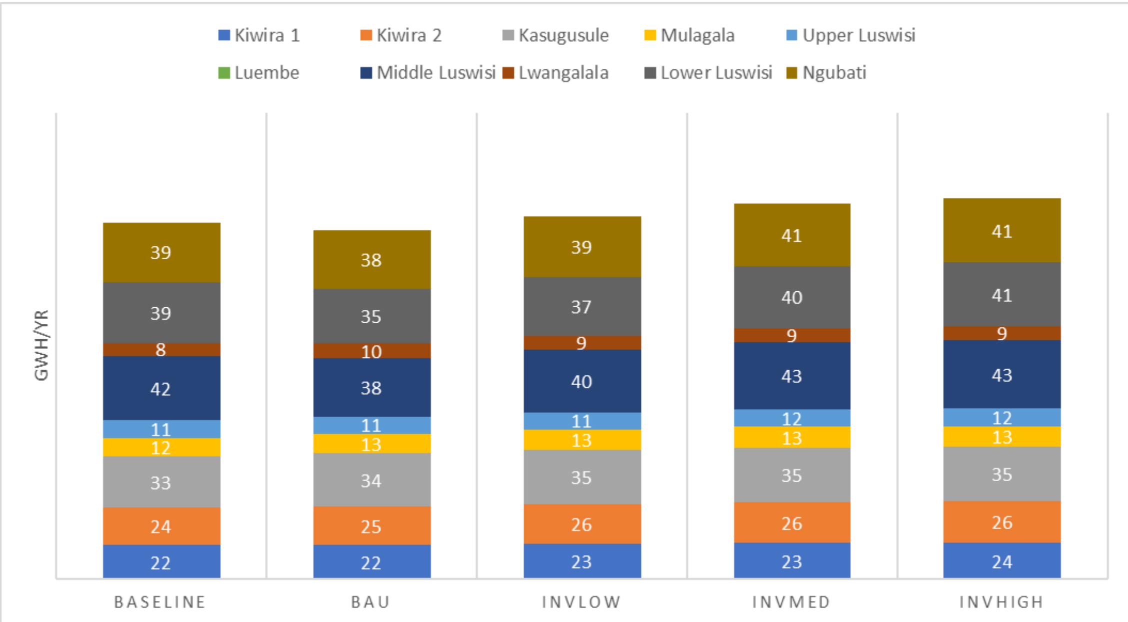


Figure 12. Hydropower generation in the Kiwira Catchment under the baseline, BaU and different SLM investment scenarios.

Table 6. Total hydropower generation (GWh/yr) for all scenarios and difference with BaU for Kiwira Catchment.

	Baseline	BaU	InvLow	InvMed	InvHigh
Total power generation	230	225	233	242	245
Difference with BaU			+9	+17	+20
Relative difference to BaU			+4%	+7%	+8%

3.3 Financial analysis: is there a business case?

A financial analysis was performed in order to assess the costs, net benefits and the return on the investments. The net-benefits are estimated from the difference between the BaU and the three SLM investment scenarios: low, medium and high.

3.3.1 Nyamindi

From the biophysical modeling results of the power generation for each of the facilities, the total power production and the corresponding total revenue can be estimated, assuming a certain electricity tariff. For the Nyamindi Catchment, the tariff that was used is 0.085 USD/kWh, which is the current feed-in tariff approved by the regulator in Kenya.

Table 7 shows the revenue for the baseline and the BaU scenario. As presented in the previous section, for this catchment the streamflow increases slightly in the future and so do power production and revenue. However, due to increased domestic water demand water availability for power generation reduces. Also, increased flows and more variable flows cause higher sediment loads affecting the efficiency of the turbines and maintenance requirements. These factors reduce the revenue by in total 0.46 million USD/yr. As Table 7 shows, the total revenue in the BaU is still 0.08 million USD/yr (1%) higher than in the baseline scenario.

Table 7. Revenue (million USD/yr) for the baseline and the future BaU scenario for the Nyamindi Catchment

	Baseline	*BaU*
Power generation (GWh/yr)	69	75
Revenue from power generation	5.86	6.40
Lost revenue due to increased domestic water demand		-0.15
Lost revenue due to increased facility maintenance costs		-0.31
Total revenue	**5.86**	**5.94**

Revenue estimates were also made for the three SLM scenarios. Table 8 shows the change in revenue change of the SLM scenarios compared to the BaU scenario. Small increases in revenue can be expected: the additional revenue is between 1% for the low investment scenario up to 3% for the high investment scenario.

Table 8. Total revenue (million USD/yr) for three SLM scenarios compared to the BaU scenario for the Nyamindi catchment

	BaU	*InvLow*	*InvMed*	*InvHigh*
Total revenue	**5.94**	**6.01**	**6.09**	**6.18**
Revenue change compared to BaU		*+0.07*	*+0.14*	*+0.24*

To assess whether the investment in sustainable land management pays back within a reasonable time horizon, a return-on-investment analysis was performed. For this, the investment costs as well as the maintenance costs of the SLM measures were considered. Figure 13 shows how benefits, costs and annual benefits are anticipated to be realized over time.

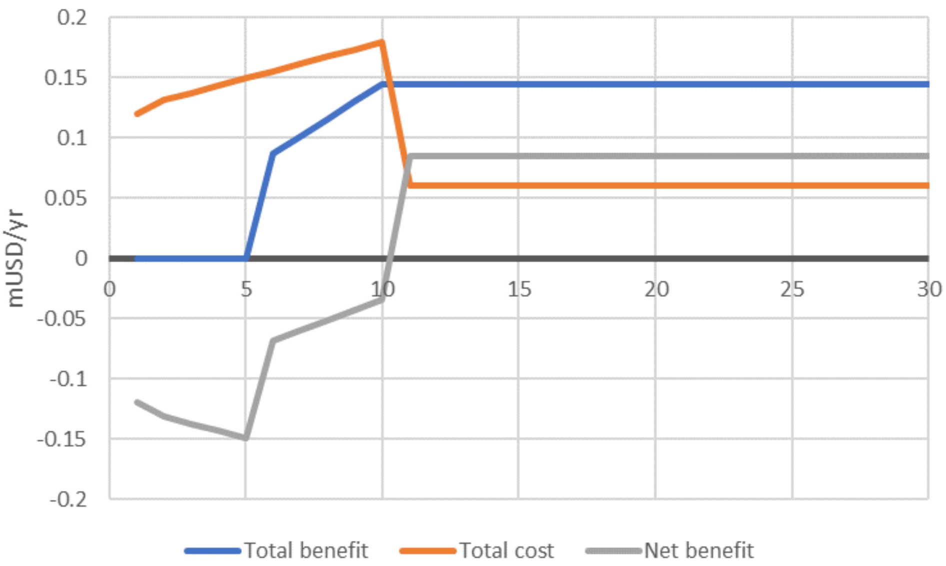


Figure 13. Total annual benefits and costs over time including continued maintenance after 10 years (in USD million) for the medium investment scenario for the Nyamindi Catchment.

The appropriate framework for considering the benefits against costs is to use discounting to convert benefits and costs into present values, which accounts for the fact that benefits and costs have different values depending on when they are realized. Figure 14 shows the same annual benefits line as in Figure 17, but also shows the Net Present Value (NPV) at any point in time. The NPV figure captures the discounted costs and benefits as they accumulate. Once the NPV line crosses above zero, the investment has reached viability. As can be seen, this does not happen within a time-frame of 30 years. So, it can be concluded that the medium investment portfolio is not financially viable.

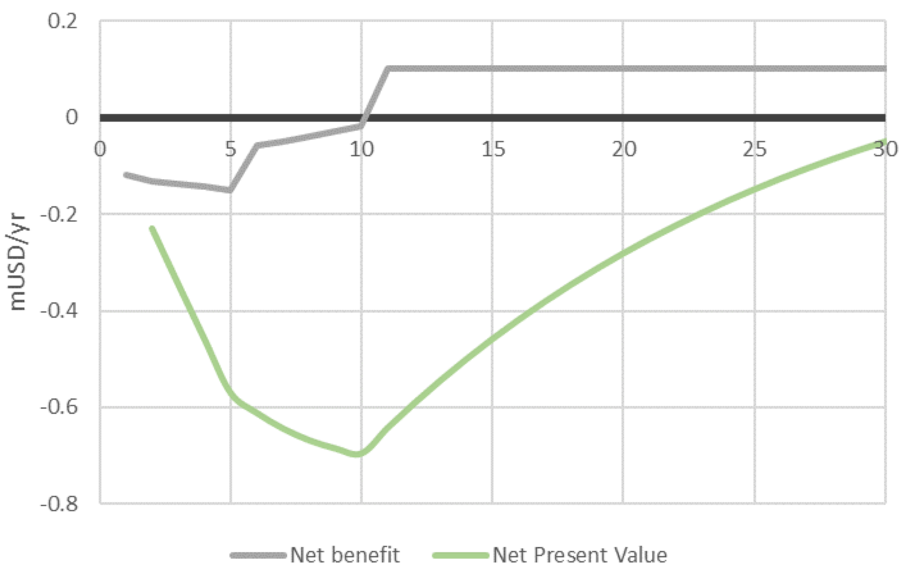


Figure 14. Annual net benefits and Net Present Value of the medium investment scenario for the Nyamindi Catchment

To assess how the return-on-investment plays out for other scenarios and assumptions, Table 9 shows the Return-on-Investment (RoI) after 20 years and 50 years, and the year for which the NPV becomes positive assuming to discount rates: 6% and 12%. This analysis is assuming the same feed-in tariff as in the previous figures (0.085 USD/kWh).

Table 9. Return-on-investment analysis for the three investment scenarios, for two time horizons and two discount rates, using the feed-in tariff approved by the regulator.

Feed-in tariff of regulator	0.085	Investment portfolio		
	Unit	Low	Medium	High
Investment costs SLM activities	*mUSD*	0.6	1.2	1.9
Revenue increase from power generation	*mUSD/yr*	0.02	0.04	0.10
Reduced turbine maintenance costs	*mUSD/yr*	0.05	0.11	0.14
RoI after 20 years	*%*	-102	-104	-99
RoI after 50 years	*%*	-33	-37	-28
NPV positive 6% rate	*yr*	48	>50	41
NPV positive 12% rate	*yr*	>50	>50	>50

To assess how this analysis depends on the tariff,

Table 10 shows the same financial analysis but based on a tariff for 5MW small hydropower facilities that is proposed in the GET FiT Zambia Initiative supported by KFW and the Government of Zambia, that consists of a premium of 1 USc, leading to a tariff of 0.12 USD/kWh.

Table 10. Return-on-investment analysis for the three investment scenarios, for two time horizons and two discount rates, using the tariff with the top-up of the GET FiT Initiative.

Top-up to the REFiT tariff	0.120	Investment portfolio		
	Unit	Low	Medium	High
Investment costs SLM activities	*mUSD*	0.6	1.2	1.9
Revenue increase from power generation	*mUSD/yr*	0.02	0.06	0.14
Reduced turbine maintenance costs	*mUSD/yr*	0.05	0.11	0.14
RoI after 20 years	*%*	-92	-94	-82
RoI after 50 years	*%*	-17	-19	2
NPV positive 6% rate	*yr*	32	34	26
NPV positive 12% rate	*yr*	>50	>50	>50

As can be seen in Table 10, the RoI is negative for 20 years horizons, but NPV becomes positive after around 30 years for the 6% discount rate. With a 12% discount rate, the investment is clearly not worthwhile.

An additional analysis was performed for one of the developers in this catchment. The most downstream facility in the Nyamindi (see Table 1) is developed by the Kenya Tea Development Agency (KTDA). Their Lower Nyamindi SHPP will not feed into the national grid but directly supply KTDA's Kimunye tea factory. KTDA currently purchases electricity at 0.18 USD/kWh from the national grid.

If the total investment costs in SLM activities are divided proportionally to installed capacity, then the majority of the investment would be covered by the upstream developer. The share of KTDA in the total investment in catchment conservation would be 10% of the total costs.

Table 11 shows that for KTDA the investment in catchment SLM activities is actually profitable. This is due to the fact they currently pay a relatively high energy price. The RoI after 20 years is positive for all investment scenarios, ranging between 72% and 137%. It is worth mentioning in this context that KTDA is already involved in catchment conservation activities. Their agricultural extension service provides support in sustainable farming practices to their smallholder tea growers/shareholders. An additional advantage for KTDA is that they become self-sufficient and independent of the national energy market.

Table 11. Return-on-investment analysis for the KTDA facility, for a 20-year time horizon

	Units	Low	Medium	High
Additional power generation	*GWh*	0.04	0.08	0.18
Increased revenue	*mUSD/yr*	0.008	0.015	0.033
Shared investment costs SLM (10% of total)	*mUSD*	0.06	0.12	0.19
Benefits for KTDA after 20 years	*mUSD*	0.15	0.30	0.66
Costs for KTDA after 20 years	*mUSD*	0.09	0.18	0.28
Net benefit for KTDA	*mUSD*	0.06	0.12	0.38
RoI after 20 years	*%*	**72%**	**68%**	**137%**

3.3.2 Kiwira

For the Kiwira catchment, the principal tariff that was used for the financial analysis is 0.129 USD/kWh, which is the current feed-in tariff approved by the regulator in Tanzania.

Table 7 shows the revenue for the baseline and the future Business-as-Usual scenario. Due to climate change and land degradation, streamflow reduces slightly and becomes more irregular, causing lower power production and reduced revenue in the future. Revenue reduces further due to increased domestic water demand and increased costs due to higher sediment loads affecting the efficiency of the turbines and maintenance requirements. In total, the total revenue in the BaU is 2.5 million USD/year lower (-9%) than in the baseline scenario.

Table 12. Revenue (million USD/yr) for the baseline and the future BaU scenario for the Kiwira catchment.

	Baseline	*BaU*
Power generation (GWh/yr)	230	225
Revenue from power generation	29.6	29.0
Lost revenue due to increased domestic water demand		-0.9
Lost revenue due to facility maintenance costs		-1.0
Total revenue	**29.6**	**27.1**

Table 8 shows the revenue change of the SLM scenarios based on the difference with the BaU scenario. The additional revenue that could be generated is between 4% for the low investment scenario up to 9% for the high investment scenario.

Table 13. Total revenue (million USD/yr) for three SLM scenarios compared to the BaU scenario for the Kiwira catchment.

	BaU	*InvLow*	*InvMed*	*InvHigh*
Total revenue	**27.1**	**28.5**	**29.8**	**30.4**
Revenue change compared to BaU		+1.1	+2.2	+2.6

Figure 15 shows how benefits, costs and annual benefits are anticipated to be realized over time. As for the Nyamindi catchment, besides the investment costs of the SLM activities, also maintenance costs were considered, as shown by the orange line after the 10-year investment period.

Figure 16 shows the same annual benefits line as in Figure 15, but also shows the Net Present Value (NPV) at any point in time. The Net Present Value line crosses above zero after 15 years, which is a reasonable time horizon for this type of investments: thus the investment (medium level) can be considered justifiable from the developers´ point of view.

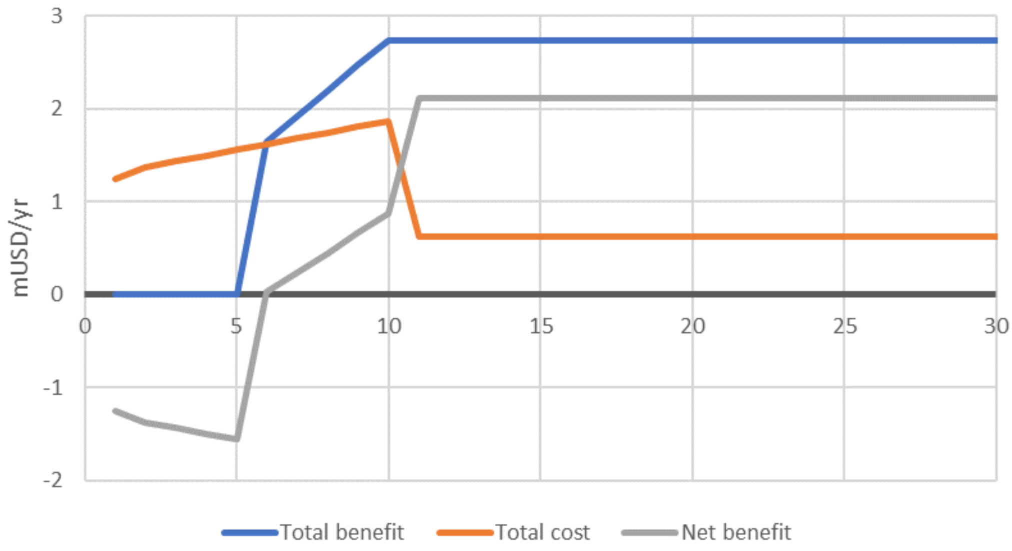


Figure 15. Total annual benefits and costs over time including continued maintenance after 10 years (in USD million) for the medium investment scenario

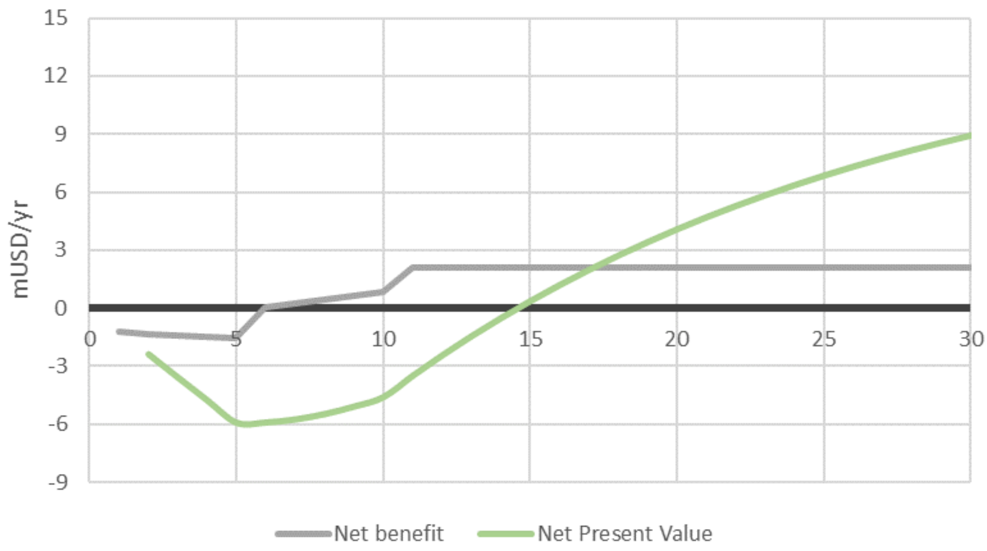


Figure 16. Annual net benefits and Net Present Value of the medium investment scenario.

Table 14 shows several other variables to assess how the time horizon and the discount rate influence the returns. This analysis is done by assuming the same feed-in tariff as in the previous figures (0.129 USD/kWh).

As can be seen, with the discount rate of 6%, all investment scenarios are profitable within a time horizon of 20 years. For a discount rate of 12%, the investment becomes considerably less attractive, especially for the high investment scenario.

Table 14. Return-on-investment analysis for the three investment scenarios, for two time horizons and two discount rates, using the feed-in tariff approved by the regulator.

Regulator-approved feed-in tariff	0.129	Investment portfolio		
	Unit	Low	Medium	High
Investment costs SLM activities	*mUSD*	6	12	19
Revenue increase from power generation	*mUSD/yr*	1.1	2.2	2.6
Reduced turbine maintenance costs	*mUSD/yr*	0.3	0.5	0.7
RoI after 20 years	*%*	-19	-26	-66
RoI after 50 years	*%*	108	96	28
NPV positive 6% rate	*yr*	15	15	21
NPV positive 12% rate	*yr*	21	23	>50

To assess how this financial viability depends on the electricity tariff, **Error! Reference source not found.** and Table 16 show two additional financial assessments. **Error! Reference source not found.** shows the analysis for a scenario in which the tariff is increased by 10%, which is in the range of what is proposed in the GET FiT Initiative. In this case, even with a discount rate of 12%, the NPV becomes positive within 20 years for the low and medium investments. In other words: under these favorable market conditions there is a clear business case for hydropower developers to invest in the catchment.

Table 16 shows the RoI for the rate that is currently being used in small power purchase agreements (PPAs) by the governmental electricity utility TANESCO, of 0.08 USD/kWh. In this case, with both discount rates, RoI is still negative after 50 years, and NPV becomes positive after a relatively long time horizon. Thus, the tariff is highly influential on the incentive to invest in improved catchment activities: under these conditions there is clearly no business case.

Table 15. As Table 14 but with an additional 10% on the regulator-approved feed-in tariff.

Regulator feed-in + 10%	0.142	Investment portfolio		
	Unit	Low	Medium	High
Investment costs SLM activities	*mUSD*	6	12	19
Revenue increase from power generation	*mUSD/yr*	1.2	2.5	2.9
Reduced turbine maintenance costs	*mUSD/yr*	0.3	0.5	0.7
RoI after 20 years	*%*	-4	-12	-55
RoI after 50 years	*%*	133	120	47
NPV positive 6% rate	*yr*	14	14	18
NPV positive 12% rate	*yr*	18	19	>50

Table 16. As Table 14 but with the current PPA price of TANESCO

Current TANESCO feed-in price	0.080	Investment portfolio		
	Unit	Low	Medium	High
Investment costs SLM activities	*mUSD*	6	12	19
Revenue increase from power generation	*mUSD/yr*	0.7	1.4	1.6
Reduced turbine maintenance costs	*mUSD/yr*	0.3	0.5	0.7
RoI after 20 years	*%*	-75	-80	-107
RoI after 50 years	*%*	13	4	-41
NPV positive 6% rate	*yr*	23	25	>50
NPV positive 12% rate	*yr*	>50	>50	>50

4 Conclusions

This study assessed impacts of sustainable land management on small hydropower investments in two different case study catchments, and analyzes the return-on-investment for the hydropower developers.

The two catchments are different in size, topography, climate and other biophysical factors, as well as socio-economic factors. Reflecting on the outcomes of both case studies, the following can be concluded:

- In the Kiwira, in a large proportion of the catchment land degradation takes place and there is scope for implementing sustainable land management activities. This makes this catchment relatively favorable for investing compared to the Nyamindi Catchment, where the possible area of intervention is smaller.
- The projected installed capacity in the Kiwira is much higher than in the Nyamindi, as such benefits accumulate and are relatively higher compared to Nyamindi.
- Climate change will be detrimental to hydropower production in the Kiwira Catchment. For the Nyamindi Catchment, the projected increase in rainfall and streamflow turn out slightly positive, even considering the impact of land degradation.
- The analysis further shows that the impacts of climate change on revenue from hydropower are in the same order of magnitude as the other negative anthropogenic factors: increased domestic water use demand in the catchment and land degradation due to poor conservation of natural areas and poor agricultural practices. However, catchment conservation activities can offset these negative impacts.

The return-on-investment analysis shows three cases, determined by the specific market conditions of the projects:

- Power generated in their Lower Nyamindi SHPP will substitute KTDA's power purchases from the national grid. Under these conditions, their investments in catchment conservation will be highly profitable, provided these costs are shared equitably across all planned hydropower projects in the catchment.
- Under favourable market conditions, e.g. provided through renewable energy programmes like the GET FiT Initiative, hydropower developers can find a viable business case to invest in catchment conservation. Under these favourable feed-in tariffs hydropower developers in the Kiwira Catchment will receive reasonable returns within their concession period. However, for the Nyamindi there is no clear business case, even under these favourable conditions.
- Under current (competitive, least-cost) market conditions for feed-in into the national grid investments in catchment conservation cannot be financially justified, considering benefits for hydropower only.

In conclusion, to ensure hydropower sustainability it is needed to:

- Implement long-term viable feed-in tariffs;
- Accept long-term investment horizons, for instance changing independent power producers' (IPP) concession periods from now typically 20 years to 30 or maybe even 50 years;
- Accept sub-commercial discount rates for investments in the environment.

This study only assessed benefits to hydropower. Obviously, improved catchment conditions lead to other economic benefits to other stakeholders: rainfed farmers due to increased soil fertility, the environment due to higher water quantity and quality, domestic, industrial and irrigation users, etc. This analysis shows that if electricity tariffs are subsidized through renewable energy initiatives, hydropower developers can be incentivized to invest in catchment conservation, leading to benefits for all related stakeholders including the developers themselves.

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Appendix I: Land cover maps

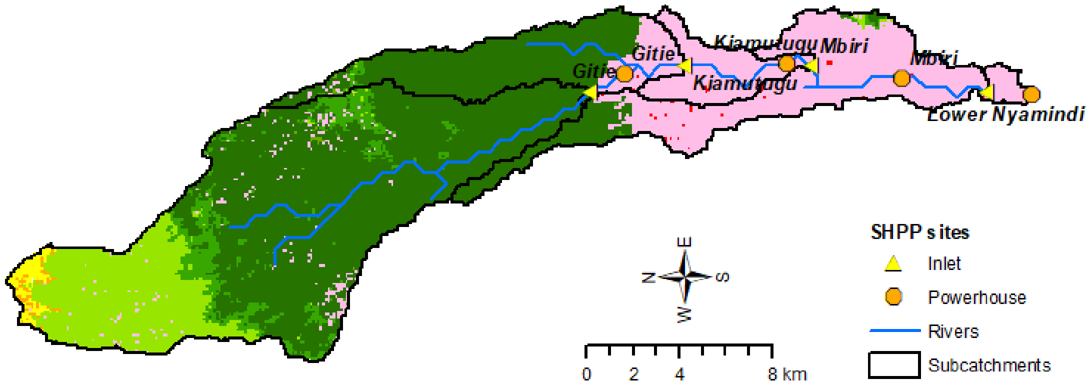


Figure 17. Land cover map of the Upper Nyamindi Catchment for the year 2015 (Copernicus Information Service, 2015), indicating locations of SHPP sites and their respective sub-catchments.

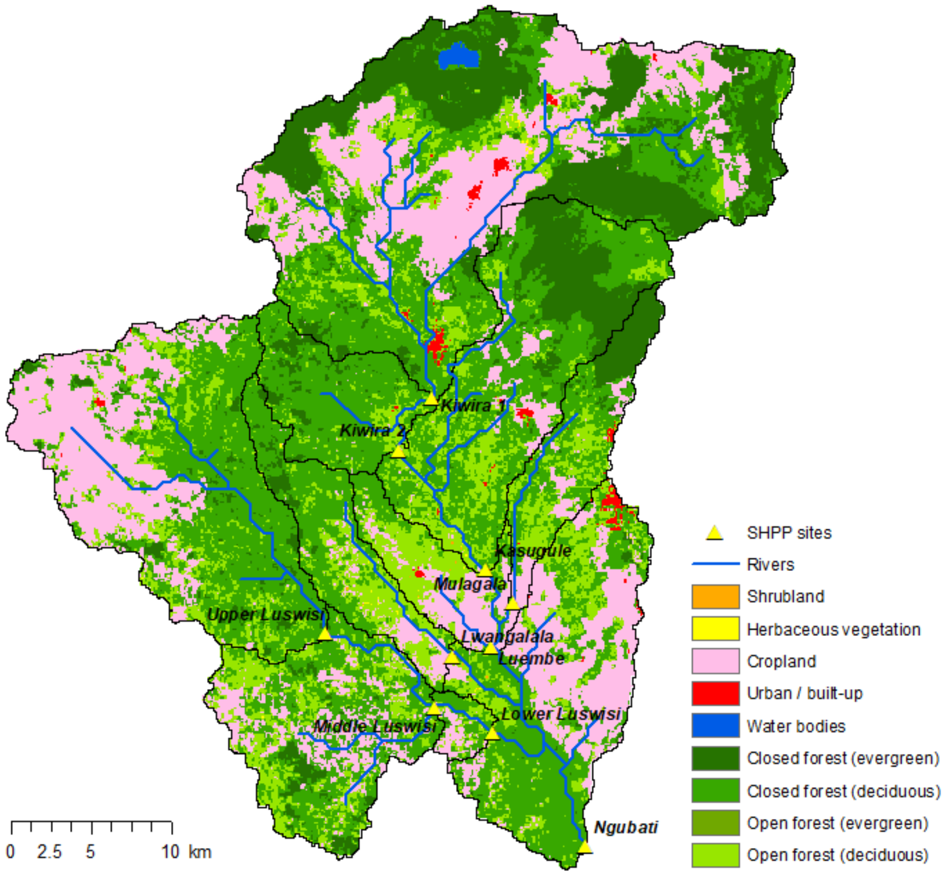


Figure 18. Land cover map of the Upper Kiwira Catchment for the year 2015 (Copernicus Information Service, 2015), indicating locations of SHPP sites and their respective sub-catchments.

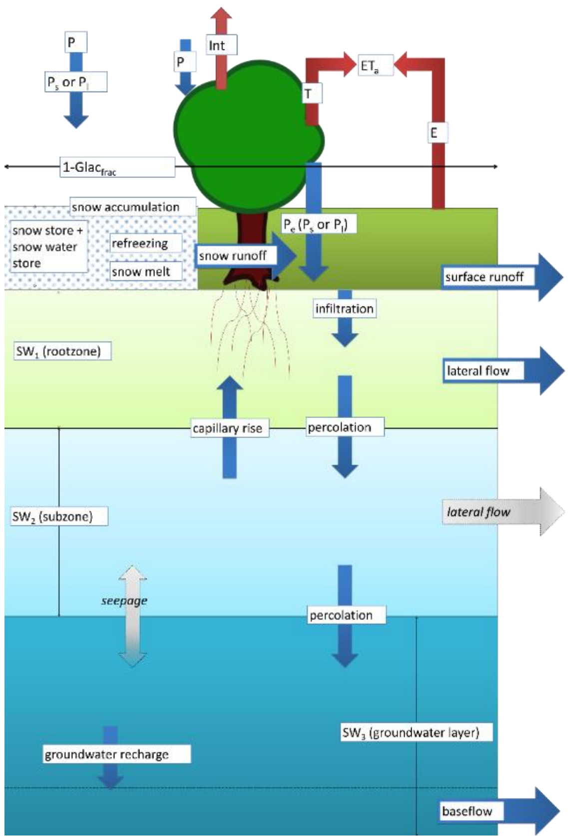
Appendix II: Biophysical modeling

II.1 Hydrological model description

Spatial Processes in Hydrology (SPHY) (Terink et al., 2015) is a hydrological model suitable and applied for a wide range of water resource management applications. It is a state-of-the-art, easy to use, robust tool, that can be applied for operational as well as strategic decision support. SPHY was developed by FutureWater in cooperation with national and international clients and partners and is meant to close the gap between the more complex hydrological models and the steady-state approaches. It is open-source and in the public domain.

SPHY has been successfully applied in various studies ranging from real-time soil moisture predictions in flat lands, to operational reservoir inflow forecasting applications in mountainous catchments, solutions to water scarcity in the Middle East, and detailed climate change impact studies in the snow- and glacier-melt dominated the Himalayan region. SPHY was developed with the explicit aim to simulate terrestrial hydrology at flexible scales, under various land use and climate conditions. The main terrestrial hydrological processes are described in a physically consistent way so that changes in storages and fluxes can be assessed adequately over time and space. Different modules are available, including an erosion and a reservoir module, which can be switched on and off depending on the specific task.

An overview of the SPHY model concepts is shown below. SPHY is grid-based and local values thus represent averages over a cell, but sub-grid variability is taken into account. The land compartment is divided in two upper soil stores and a third groundwater store, with their corresponding drainage components: surface runoff, lateral flow and base flow. Any precipitation that falls on land surface can be intercepted by vegetation and in part or in whole evaporated. The snow storage is updated with snow accumulation and/or snow melt. A part of the liquid precipitation is transformed in surface runoff, whereas the remainder infiltrates into the soil. The resulting soil moisture is subject to evapotranspiration, depending on the soil properties and fractional vegetation cover, while the remainder contributes on the long-term to river discharge by means of lateral flow from the first soil layer, and base flow from the groundwater reservoir.



As input, SPHY requires data on state variables as well as dynamic variables. The most relevant state variables are Digital Elevation Model (DEM), land use type, glacier cover, reservoirs and soil characteristics. The main dynamic variables are climate data such as precipitation, temperature, reference evapotranspiration. In addition, the dynamic vegetation module relies on satellite-based vegetation data in order to simulate the temporal variability of soil-water-vegetation-atmosphere interactions. More information and documentation can be found on www.sphy-model.org.

II.2 Model valibration

The SPHY model provides estimates for all hydropower locations of daily streamflow over multiple years. Valibration of the SPHY model for streamflow in Kiwira River was performed based on available flow gauge data for the Kiwira Town and Natural Bridge measurement sites. Figure 19 shows measured and modeled discharge for Kiwira Town, indicating that seasonal flow variability in both time series is similar. In terms of absolute values seeming discrepancies between measured data of the two stations were observed. The long-term water balance of the Kiwira catchment was therefore checked against satellite-derived actual evapotranspiration (ET) of the SSEBop product. Catchment-averaged Annual ET for 2003 – 2017 was found to be 960 mm according to the SPHY results, where SSEBop indicates 992 mm. This deviation of only 3.2% was found to be a satisfactory indication of model skill to predict partitioning of rainfall into ET and runoff.

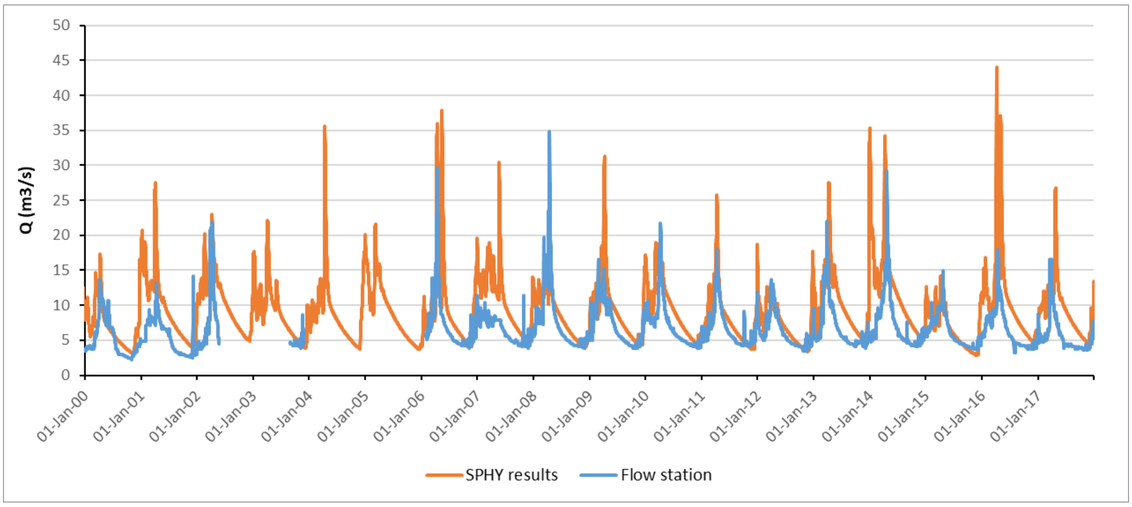


Figure 19. Measured and modeled daily discharge at Kiwira Town.

For Nyamindi, no flow gauge data was available and the model was calibrated and validated solely based on satellite-derived ET from SSEBop. The calibrated model slightly overestimated annual average ET by 4% (1039 mm vs. 998 mm), indicating satisfactory performance.

Given the lack of reliable sediment load data in these catchments, the sediment loads were estimated based on so-called sediment rating curve: a relationship between streamflow and sediment load. The rating curve used for this study was extracted from previous work in the Upper Tana (Hunink et al., 2013).

II.3 Hydropower calculations

Hydropower generation is computed from the flow passing through the turbine, based on SPHY simulated flows at the intakes of the run-of-river plants, and constrained by the turbine's maximum flow capacity.

Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of pressure head and volume flow rate.

For this analysis, the same equations are as those that are implemented in the Water Evaluation and Planning (WEAP) tool developed by the Stockholm Environment Institute and often used for basin-scale water resources and hydropower assessments (Droogers, 2009; Hunink et al., 2017). First, the so-called *HydroGenerationFactor* is calculated which is a function of the mass of water (1000 kg/m^3) through the turbines multiplied by the drop in elevation, the plant factor (fraction of time on-line), the generating efficiency, and a conversion factor (9.806 kN/m^3 is the specific weight of water, and from joules to gigajoules):

$HydroGenerationFactor_H = 1000\ (kg / m^3) * DropElevation_H \times PlantFactor_H \times PlantEfficiency_H * 9.806 / (1{,}000{,}000{,}000\ J / GJ)$

The *PlantEfficiency* factor was assumed to be 0.90, which is a typical value for hydropower turbines. The *PlantFactor* (fraction of time on-line) was assumed to be 1.

Then, from the data on planned installed capacity, and the $HydroGenerationFactor_H$, the maximum turbine flow was calculated:

$MaxTurbineFlowGJ = InstalledCapacityMW / (HydroGenerationFactor_H \times 1000)$

There is typically also a minimum turbine flow, which depends on the turbine design and other factors. For this analysis it was assumed that the minimum turbine flow is 25% of *MaxTurbineFlowGJ.*

Then, the flow through the turbines from the daily simulated streamflow, assuming that only the *MaxTurbineFlowGJ* is diverted at the intake.

$FlowThroughTurbine = Min(\ Release_H\ ,\ MaxTurbineFlow_H\ )$

Finally, the gigajoules (GJ) of energy produced in a timestep are calculated by:

EnergyFullTimestepGJH = FlowThroughTurbineH x NoSecondsTimestep x HydroGenerationFactorH

Appendix III: Business-as-usual scenario parameters

III.1 Land degradation

Table 17 shows the relative changes of four SPHY model parameters of the BaU scenario compared to the baseline scenario. These values were based on remote sensing-based land degradation analysis and expert knowledge.

Note that the changes in the Kiwira are applied to the entire catchment, as the analysis demonstrated that land degradation occurs in most parts of the catchment. The changes for the Nyamindi catchment are only applied within a 3km distance from the boundary of the Natural Reserve, as this is where the land degradation occurs principally in this catchment.

Table 17. Parameterization of land degradation in the BaU model simulations. Values given relative to the baseline conditions.

Parameter	Kiwira	Nyamindi
NDVI	-0.05	Reduced in 3 classes (-0.05, -0.1, and -0.15)
Rooting depth	-25%	Reduced in 3 classes (-10%, -25%, and -40%)
Gw delay	-25%	-25%
Kx	-0.2	-0.2

III.2 Competing domestic water use

Water use was assumed to increase linearly with population growth. For Kiwira, population density (124 persons / km^2) and population growth (2.5%) were derived from the catchment IWRM plan (LNBWB, 2015). A water consumption of 100 liters per capita was assumed, based on typical values considered in water supply projects in Kenya. For the Nyamindi catchment, the population density for 2015 (154 persons / km^2) was extracted from the WorldPop dataset[1]. Annual population growth (4.5%) was derived from the same dataset, based on the difference between the years 2015 and 2015. For both catchments, the year 2038 was used as the reference year for calculating additional domestic water use, associated reductions in water availability, and lost revenue to hydropower operators.

III.3 Climate change projections

To account for climate change in the BaU model run, climate projection data was obtained from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset. The NEX-GDDP dataset is comprised of downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs). The CMIP5 GCM runs were developed in support of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The NEX-GDDP dataset includes downscaled projections for RCP 4.5 and RCP 8.5 from the 21 models and scenarios for which daily scenarios were produced and distributed under CMIP5. Each of the climate projections includes daily maximum temperature, minimum temperature, and precipitation for the periods from 1950 through 2100. The spatial resolution of the dataset is 0.25 degrees (~25 km x 25 km).

[1] http://www.worldpop.org.uk/data/summary/?doi=10.5258/SOTON/WP00124

In the SPHY runs simulating BaU and SLM activities, baseline precipitation and temperature data from the sources listed in Table 3 were transformed based on delta-change factors for minimum temperature, maximum temperature, and mean daily rainfall as derived from the NEX-GDDP dataset. To incorporate projected changes in extreme rainfall events (and corresponding peak flows), the daily rainfall map series for Kiwira was transformed based on an additional delta-change factor for the 99th percentile of daily rainfall. For Nyamindi, changes in temporal rainfall variability were implemented by attributing the projected change in annual mean rainfall specifically to the 6 wet months. Figure 20 presents some key climate parameters for Kiwira and Nyamindi, obtained by averaging the different GCMs included in NEX-GDDP.

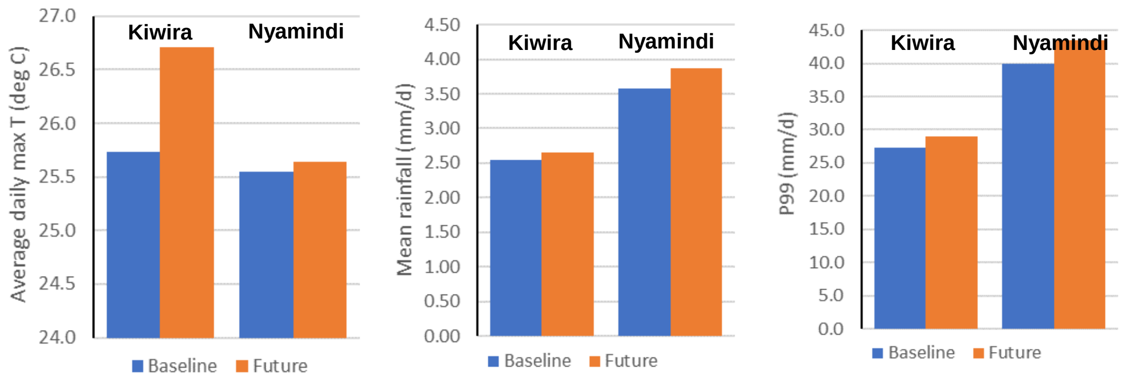


Figure 20. Daily maximum temperature (l), mean daily rainfall rainfall (m) and 99th percentile (r) of daily rainfall obtained by averaging outputs of GCMs included in the NEX-GDDP dataset. Baseline refers to the 1991 – 2020 period, future to 2021 – 2050.

Appendix IV: SLM scenario modelling assumptions

IV.1 Parameterization of SLM activities

Table 18 shows an overview table of the SLM activities and their respective model parameter changes, for the three investment levels (low, medium high). Also the criteria for locating the activities are listed.

Table 18. Overview of how the SLM activities were included in the SPHY model: associated model parameter changes and criteria used for their location. Recession coefficient values (Kx) are provided in absolute values. All other values and percentages are relative to the BaU values.

NYAMINDI						
Investment portfolio: LOW						
Landcover	**NDVI**	**Rooting depth**	**Gw delay**	**Slope**	**Kx**	**Location**
Terracing	0.00	0%	30%	-30%	0.667	Agr slope > 12%
Road mitigation	0.00	5%	10%	-2.5%	0.667	Unpaved roads
Riparian management	0.025	10%	25%	0%	0.667	100 m buffer streams
Other (Agroforestry, grass strips, mulching)	0.025	10%	10%	0%	0.667	Other agriculture
Forest conservation	BL+0.5*BaU_red	100-85-70%*BL	20%	0%	0.667	Forest in border zone
Investment portfolio: MEDIUM						
Land management	**NDVI**	**Rooting depth**	**Gw delay**	**Slope**	**Kx**	**Location**
Terracing	0.00	0%	30%	-30%	0.733	Agr slope > 10%
Road mitigation	0.00	10%	20%	-5%	0.733	Unpaved roads
Riparian management	0.05	25%	40%	0%	0.733	100 m buffer streams
Other (Agroforestry, grass strips, mulching)	0.05	25%	20%	0%	0.733	Other agriculture
Forest conservation	BL	BL	30%	0%	0.733	Forest in border zone
Investment portfolio: HIGH						
Land management	**NDVI**	**Rooting depth**	**Gw delay**	**Slope**	**Kx**	**Location**
Terracing	0.00	0%	30%	-30%	0.8	Agr slope > 8%
Road mitigation	0.00	20%	30%	-10%	0.8	Unpaved roads
Riparian management	0.075	40%	50%	0%	0.8	100 m buffer streams
Other (Agroforestry, grass strips, mulching)	0.075	40%	30%	0%	0.8	Other agriculture
Forest conservation	BL+0.025	BL+10%	40%	0%	0.8	Forest in border zone

KIWIRA						
Investment portfolio: LOW						
Land management	**NDVI**	**Rooting depth**	**Gw delay**	**Slope**	**Kx**	**Location**
Terracing	0.00	0%	30%	-30%	0.75	Agr slope > 12%
Road mitigation	0.00	5%	10%	-2.5%	0.75	Unpaved roads
Riparian management	0.025	10%	25%	0%	0.75	100 m buffer streams
Other (Agroforestry, grass strips, mulching)	0.025	10%	10%	0%	0.75	Other agriculture
Forest conservation	0.025	10%	20%	0%	0.75	All forest
Investment portfolio: MEDIUM						
Land management	**NDVI**	**Rooting depth**	**Gw delay**	**Slope**	**Kx**	**Location**
Terracing	0.00	0%	30%	-30%	0.825	Agr slope > 10%
Road mitigation	0.00	10%	20%	-5%	0.825	Unpaved roads
Riparian management	0.05	25%	40%	0%	0.825	100 m buffer streams
Other (Agroforestry, grass strips, mulching)	0.05	25%	20%	0%	0.825	Other agriculture
Forest conservation	0.05	20%	30%	0%	0.825	All forest
Investment portfolio: HIGH						
Land management	**NDVI**	**Rooting depth**	**Gw delay**	**Slope**	**Kx**	**Location**
Terracing	0.00	0%	30%	-30%	0.9	Agr slope > 8%
Road mitigation	0.00	20%	30%	-10%	0.9	Unpaved roads
Riparian management	0.075	40%	50%	0%	0.9	100 m buffer streams
Other (Agroforestry, grass strips, mulching)	0.075	40%	30%	0%	0.9	Other agriculture
Forest conservation	0.075	30%	40%	0%	0.9	All forest

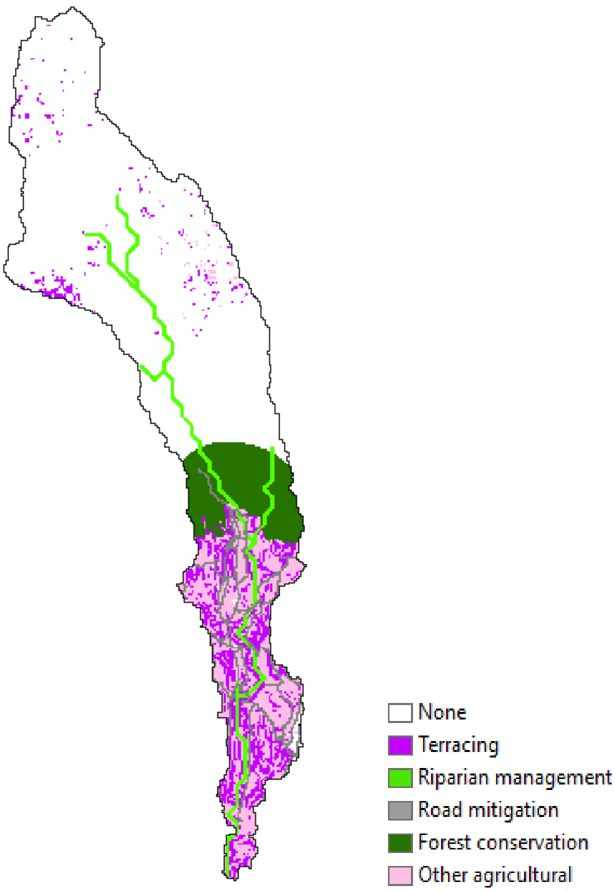


Figure 21. Location of SLM activities in Nyamindi under the high investment scenario.

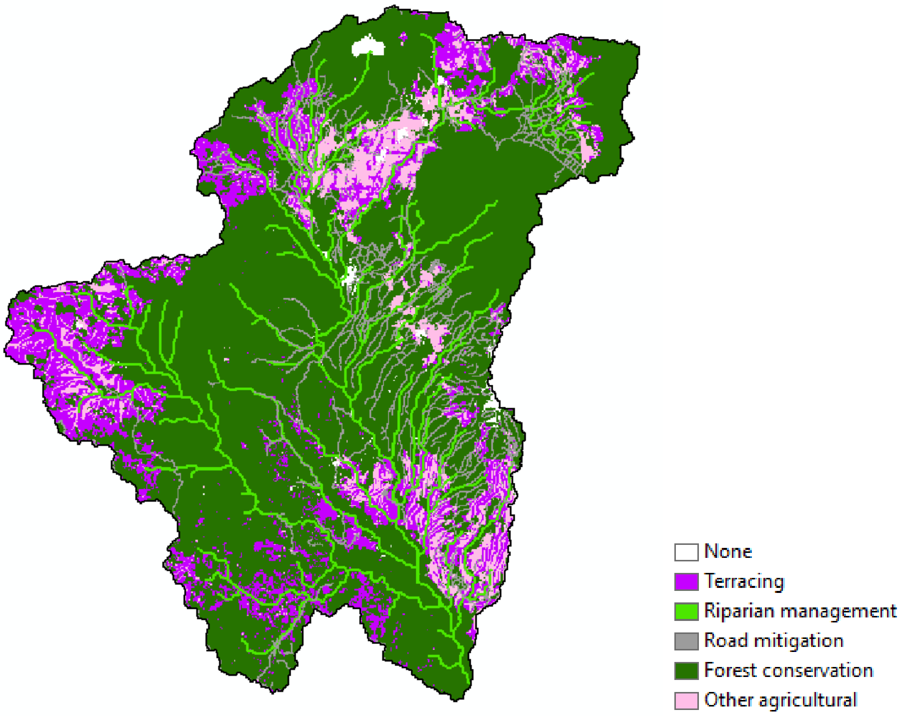


Figure 22. Location of SLM activities in Kiwira under the high investment scenario.

Table 19. Total area intervened (km²) per SLM activity in the Nyamindi catchment

Activity	**Low**	**Medium**	**High**
Terracing	8.2	12.9	20.4
Riparian management	10.4	10.4	10.4
Road erosion mitigation	10.1	10.1	10.1
Forest conservation	20.2	20.2	20.2
Other agricultural SLM	41.3	36.6	29.0
Total	**90.1**	**90.1**	**90.1**

Table 20. Total area intervened (km²) per SLM activity in the Kiwira catchment

Measure	**Low**	**Medium**	**High**
None	10	10	10
Terracing	142	172	204
Riparian management	106	106	106
Road erosion mitigation	91	95	100
Forest conservation	921	921	921
Other agricultural SLM	179	145	108
Total	**1450**	**1450**	**1450**

For the costing of investments in SLM activities, values were taken from literature and principally from the Upper Tana Nairobi Water Fund business case study (Apse et al., 2015; Norton-Griffiths and Southey, 1995). Table 21 shows the unit costs for each SLM activity. The table also includes a column which lists for each of the activities the percentage of the landcover on which the actual intervention is assumed to take place, and thus the unit cost rate applies. For example, for terracing it assumed that the actual implementation works are performed on 50% of the targeted area, principally excluding settlements, tracks, and areas which for other reasons are not adequate for being terraced. For the road mitigation, this value is 20%: the area of influence from unpaved roads is assumed to be 100m broad (50m on both sides of the road) while it is assumed that the actual implementation of erosion mitigation activities is concentrated in a 20m strip

Table 21. Unit costs for establishing the SLM activity (USD/ha) used for both catchments

SLM activity	USD/ha	% intervened area
Riparian management	1,000	50%
Forest conservation	50	50%
Terracing	300	50%
Other agricultural SLM	200	30%
Road erosion mitigation	4,000	20%

Appendix V: Annual NDVI values in Kiwira Catchment

Figure 23. Annually averaged NDVI values for the Kiwira Catchment, as derived from high-resolution satellite imagery.