Preliminary Hydrological and Agronomic Study for a Payment for Watershed Services Scheme in Rwenzori Mountains National Park, Uganda

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Summary

This report summarizes the activities and outcomes of a pilot study that assesses the hydrological and agronomic factors for the development of a Payment for Ecosystem Services scheme in two watersheds (Mubuku and Nyamwamba) that have their headwaters in the Rwenzori Mountains National Park. Based on field data, mapping and modeling, the principal watershed services are assessed, interaction between upstream interventions and downstream services are assessed and priority areas and interventions are identified. The study also delivers a database and a monitoring plan.

Overall, the study shows that there is scope for the implementation of a PES scheme, from a hydrologic and agronomic perspective. The hydrologic response of the watersheds (water quantity and quality) is very dependent on the activities developed in the agricultural area. Simulations have confirmed that interventions in the agricultural area can significantly influence flows and sediment yield. Low flows can increase during the dry season and high peak flows can potentially reduce, when targeting especially the steepest slopes in the area. Adoption of sustainable land management practices is currently low: promoting its uptake by upstream farmers through the PES scheme can lead to benefits to hydropower, irrigation and domestic and industrial water supply.

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1 Introduction

1.1 Background

The Rwenzori Mountains National Park (RMNP) is a key natural resource, safeguarding drinking water for around 2 million people, and supplying water for a variety of industrial users including several hydropower and mining companies. These water dependent industries are key economic growth engines and major employers in the region and beyond.

The watershed services of the RMNP are currently undervalued and under increasing threat from climate change and increasing intensity of land use. Current land use practices, dominated by small holder farmers, are leading to loss of soil and reduce water quality and water quantity.The erosion and variable water flows puts at risk the reliability of the downstream services (hydropower and mining) and water supply.

Figure 1. The Nyamwamba watershed, facing the Rwenzori Mountains National Park

World Wide Fund for Nature (WWF) has in the recent years recognized the strong links between conservation and sustainable use of biological diversity, and the eradication of extreme poverty. Currently WWF Uganda is implementing “Sustainable Financing of the Rwenzori Mountains National Park (SFRMNP) Project” with funding from the European Union (EU) and the French Funds for Global Environment (FFEM).

This project pilots a Payment for Ecosystem Services (PES) scheme that should engage large, downstream users (corporations and utilities) that willingly contribute to a water conservation scheme as a way of shoring up their business investments. The goal of the pilot is to study the feasibility of the PES scheme in the watersheds of the Mubuku and Nyamwamba rivers and supporting nature conservation and a healthy watershed that improves the livelihoods of landowners and provides a sustainable supply of the critical quantity and quality of water to downstream water users, to local communities as well as to industrial users, including the hydropower and mining sector.

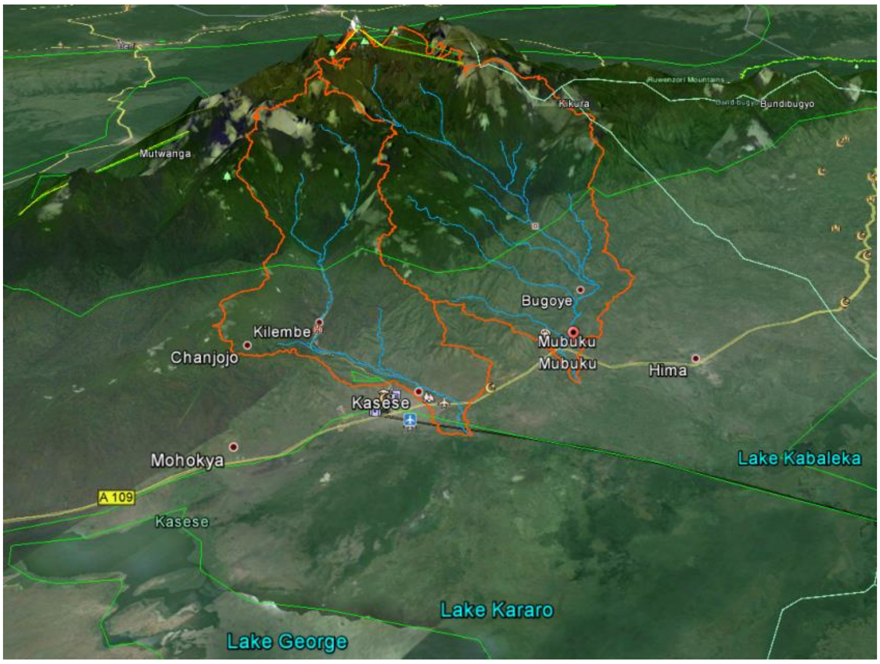

Figure 2. Location of the study area in the Rwenzori Mountains National Park (source: Google Earth)

To understand the value of the resources and what interventions are required to protect those, a study is required to map the resources, stakeholders, and drivers to behaviour change and management change in the study area.

1.2 Ecosystem services

1.2.1 Biophysical setting

The Rwenzori Mountains National Park (RMNP) extends over approximately 995 km^2 along the border between Uganda and the DRC, on the equator. This ecosystem is part of the Greater Virunga Landscape and the Albertine Rift. The RMNP ranges between 1,600 and 5,109 m in altitude with several peaks exceeding 4,800 m, notably mounts Stanley, Speke, and Baker. It is the wildest and least traveled of all the African high-altitude massifs.

The climate of RMNP is tropical, affected by seasonal movements of the inter-tropical convergence zone and by altitude and topography (Howard 1991). There are two rainy seasons each year from March to May and from August to December (Osmaston and Pasteur, 1972). Most of the plains at the foot of the range lie in a rain shadow and get as little as 750mm of rain a year.

The Rwenzori's fauna and flora is not very diverse because of the harsh climatic conditions, but its ecosystems offer a unique refuge for a certain number of species endemic to mountain environments. The Rwenzori is home to approximately 25 plant, 18 bird, and 12 mammal endemic species. The Rwenzori leopard (endemic subspecies), the red duiker, and the three-horned chameleon are just a few examples. The RMNP is considered an Important Bird Area, and includes nine species of large mammals in the park, including three primates: the Chimpanzee, the Blue Monkey, and the Rwenzori Colobus. The population of chimpanzees is estimated at more than 350 individuals. The RMNP is home to a succession of very specific habitats, including one of the richest Afromontane forests, Afro-alpine grassland rich in giant lobelias, heathers, and groundsels as well as a polar ice cap today limited to one km².

1.2.2 Water and land users

According to the 2012 population census, 805,000 people live in the 22 sub-counties adjacent to the RMNP, and the population is growing at a rate of around 3.8% per year. In the area targeted by the project's PES component, this growth is closer to 5.5% per year compared to a national average of 3.3%. There is a high poverty rate, standing at between 15 and 30% of the rural population under the definition given by the World Resources Institute, but comparatively less than in other parts of Uganda, particularly in the north. The park's buffer zone is relatively unurbanized, except for the cities of Kasese and Fort Portal and the urban centers sprouting along the road from Fort Portal to the DRC.

Figure 3. Irrigated area downstream in the Nyamwamba watershed

The main activity in the vicinity of the RMNP is still subsistence farming, plantain, beans, cassava, and millet. Rwenzori coffee production is internationally renowned, but it is still farmed on a small, unorganized scale and ineffectively marketed. Livestock farming is uncommon. More intensive agriculture of maize, tea, sugar cane, and cotton is practiced at lower altitudes moving away from the RMNP, sometimes on irrigated land. These activities also depend on the park's water resources. Further downstream still, the Rwenzori rivers feed Lake George in the south and Lake Albert in the north. These lakes are a very important source of protein, but the fishery resources of Lake George in particular are on the decline due to overfishing and to the siltation caused by poorly managed watersheds.

The cultivated land in the high valleys near the park has been eroded, with slopes of on average 25%. Although they benefit from a relatively humid climate, yields are limited due to fragile soils and farming techniques that accentuate their degradation. The tree cover of the Kasese District has fallen to 5%. Cultivated land parcels are often small (2 acres on average). Property is owned by individuals, but the district does not issue title deeds because few farmers have the funds needed to obtain this certificate. However, customary law as practiced in the Rwenzori's foothills does not appear to prevent land transactions and investment. The local authorities know who owns each parcel and recognizes these owners. There are few land disputes, other than among families, and there are no breeders or transhumant farmers, which means there is little competition for different uses of the same land.

The Rwenzori region is still an agricultural area, but it is dominated by two major types of industry: hydropower and the mining/cement industry. They are the region's main source of formal employment, with for example Hima Cement employing 350 permanent staff and the hydropower plants of Kasese Cobalt and Tronder employing about 50 permanent staff each.

Figure 4. Dam in Sebwe river for diversion to Mubuku Irrigation Scheme

Hima Cement, already the leading cement plant in Uganda (850,000 t/yr), is considering expanding soon, while the concession of the major Kilembe copper mine has just been attributed to the Chinese company Hima Tibet, which should begin exploiting the deposit again having been on hold since the 1980s. The area includes four hydropower plants of which three are currently in operation.

All these industries depend on the Rwenzori Mountains for their water supply. Each has obtained a permit for water extraction and pays water fees to the central government in addition to concession royalties. All the major companies are therefore members of the Water User Associations (WUA).

Downstream some areas are under irrigation. The largest is the Sebwe Irrigation Scheme, that diverts water from the Sebwe river, and includes an irrigation reservoir. From the Nyamwamba some farmers divert water without legal permission to irrigate crops.

1.2.3 Challenges faced

The area faces challenges related to climate change and demographic pressure, but also to unsustainable land use in the area. There is a high deforestation rate and cultivation of unsuitable land on steep slopes and river banks. Also there is poor agronomic dissemination and support for farmers for best practices and yields. Due to the high poverty, there is low investment capacity of farmers. In some areas, reforestation happens with species that are inadequate and highly water-consumptive (eucalyptus). Another threat to the area is the leachate from the Kilembe mine which is likely to increase when extraction activities are upscaled in the near future.

Overall, these unsustainable land use practices cause loss of soil fertility through erosion, costs to hydropower companies through the abrasive impacts of sediments, sedimentation issues for water utilities and water infrastructure (dams, reservoirs), more peak flows, increasing flooding risk, and reducing baseflows affecting hydropower production. Also, the increasing occupation of riverine areas causes bank instability and significant damage and sediment loads when the water level rises during the rainy season.

As a possible solution to these challenges, WWF is proposing the implementation of a Payments for Ecosystem Services (PES) scheme. This is a conservation funding tool in which beneficiaries of an ecosystem service remunerate those “producing” it, or at least encourage them not to degrade it. This includes paying for “producers” to put an end to certain practices in order to preserve an ecosystem service, in particular certain agricultural and land use practices. It is therefore necessary to compensate for the opportunity costs associated with changing these practices. Also the terms “Payment for Watershed Services, “Green Water Credits” or “Water Towers” are often used instead of PES when it focuses on water-related services.

PES schemes are a contractual, voluntary, or conditional economic instrument. A wide variety of mechanisms can qualify as a PES, including those in which the beneficiaries do not pay voluntarily (carbon, park entrance fees, etc.), or all beneficiaries do not contribute, or the payment is made by a third party (project or state), which acts as a substitute for the service beneficiaries.

Figure 5. Hydropower plant (Mubuku I) and surrounding agricultural lands in the Mubuku watershed

1.3 Objectives

The aim of this pilot study as described in this report is to provide a sound justification for the development of a Payment for Ecosystem Services scheme in two watersheds (Mubuku and Nyamwamba) that have their headwaters in the Rwenzori Mountains National Park. Based on hydrological and agronomic data, mapping and modeling, the principal watershed services are assessed, priority areas and interventions will be identified, and the monitoring plan will be defined.

This preliminary study identifies areas in the watersheds that are likely to impact and benefit the primary stakeholders (farmers, hydropower, mining and water utilities), and at the same time promote the conservation of the ecological systems of the Rwenzori Mountains National Park.

More specific, the objectives of this study are to

- Map and assess origin of the water-quantity and quality problems. This will lead to the identification of the ecosystem services that are critical to primary stakeholder interests.

- Carry out a scoping modeling assessment to understand potential benefits on downstream services of possible interventions upstream.
- Identify the main stakeholders in the areas by workshops, stakeholder consultations and capacity building activities.
- Build a database with a reporting tool that can be used by local institutions and stakeholders with all relevant data to support the PES scheme.
- Develop a proposal for a monitoring program.

Based on this preliminary study a more detailed design study phase should be initiated. Such a detailed design study is the predecessor of the implementation phase.

2 Methodology

2.1 General approach

This study combines field data collection, surveys and stakeholder consultation with data analysis and simulation studies. The aim is to study the feasibility of the PES scheme from a biophysical perspective, answering the following key questions:

- Where are the key areas that influence the provided services and where can they be enhanced?
- Which interventions and sustainable land management practices are feasible options for the PES scheme?
- What is the level of impact that can be expected
- Can this be significant and beneficial to potential downstream beneficiaries of the PES scheme?

To answer these questions, the following activities and tools are developed in this preliminary study:

1. Baseline field survey, streamflow sampling
2. Agronomic assessment
3. Land cover change based on satellite data
4. Water resources analysis and simulation
5. Stakeholder analysis
6. Database and reporting

The following sections detail the methodology followed for each of these activities. Chapter 3 presents the results. Appendix I includes the Monitoring Plan.

2.2 Baseline data from field sampling

The sampling design on the rivers followed a longitudinal gradient from upstream to downstream areas. The upstream areas represented the pristine or reference conditions where it was assumed that human activities were minimal and therefore pollution and sediment load were minimum.

River Nyamwamba sites

1. The first site on river Nyamwamba is located inside Rwenzori Mts National Park boundary where human activities are limited. Above the sampled site, there was a landslide site from the past that could be a source of sediment to the river.
2. River Mulyambuli a tributary of river Nyamwamba was sampled at a point just before it joins the main river. It is characterized by clearly waters.
3. River Nyamwamba at Masule foot bridge. The site is located just before the river flows through the Hima Tibet mining company complex. It represents relatively un-degraded catchment and lightly settled area close to the park boundary. About 200m downstream is the proposed weir for a mini hydropower plant.
4. Nyamwamba river below the Kiwa Hotsprings. The river at this point drains the mining area and heavily cultivated hill slopes that can be described as hot spots of erosion.
5. Nyamwamba above the railway crossing. The river at this point represents a heavily silted stream as a result of human activities upstream such sand mining, stone

quarrying, watering of livestock and car washing. As a result, the site might be the most polluted of all the sampled sites on river Nyamwamba.

River Mubuku sites

River Mubuku is the largest river draining the Rwenzori Mountains complex. It has several tributaries such as Bujuku, Kyoho, Kanywankoko, Kithakena, and Ruboni. The river has been much dissected outside the park where three weirs have been constructed for hydropower generation. The power companies diverting water from the river include Mubuku I operated by Hima and Tibet (Formerly Kilembe mines), Mubuku II operated by Bugoye Power Company Ltd (Formerly Tronder Power), and Mubuku III operated by Kasese Cobalt Company Ltd).

1. Mubuku inside the park. The site is located above the foot bridge to Buraro (also called the third boys’ bridge). The site represents reference conditions draining upstream areas located within a national park.
2. Kyoho stream at the falls. Kyoho stream is a tributary of River Mubuku with clearly waters unlike the Mubuku water that is coloured with a tinge humic acids. It was also sampled to represent pristine conditions.
3. Mubuku river above Kilembe weir. The site is located in community land and the upstream catchment area is relatively pristine as it is close to the park boundary and also buffered by a reserved forest that is owned by ECOTRUST Uganda, a conservation NGO. The river segment was characterized by fast flows.
4. River Mubuku below Kilembe dam. The site is less than a km from Kilembe dam and it was established to give an indication of how much water the Kilembe dam diverts from the River.
5. River Mubuku before Bugoye dam. The site is located in community land and sampling was done above the weir for the Bugoye power dam. It was sampled to gauge how much water is in the river before it is diverted to generate power downstream. Flows were also measured immediately below the weir to gauge how much water is left in the river after the diversion.
6. Kithakena stream (tributary of river Mubuku). The site was sampled to gauge how much water it contributes to the flows in river Mubuku but also assess how much sediment is generated from the catchment it drains.
7. River Mubuku at Rwakingi. This represents conditions in the river when all the power dams have diverted water from the system. It was also designated to estimate sediment load from mostly hilly slopes.
8. River Mubuku below KCCL outflow channel. This represents conditions when water has all been returned to the system. It is an area that is prone to flooding because of the increased flow especially during the rainy seasons.
9. River Sebwe near park boundary. This was sampled to represent relatively pristine conditions in river Sebwe as it flows from the park. The river supplies water to the Mubuku Irrigation Scheme but also drains steep terrain and may thus carry a lot of sediment from the landscape.
10. River Sebwe above the Mubuku Irrigation scheme dams. This was sampled to represent conditions in the stream just before the water is diverted to the irrigation scheme.

Water quality methods

Water quality variables measured onsite included

- dissolved oxygen (mg/l),
- pH,
- electrical conductivity (µS/cm),
- turbidity (NTU),

- Oxidation-reduction potential (ORP, mV),
- total dissolved solids (TDS) and
- Temperature.

The variables were measured using a Horiba U-50 Multiparameter Water Checker.

Other water quality variables such as ions and nutrients such as phosphates and nitrates, water samples were taken to the laboratory for analysis using a Spectrophotometer. Microbiological variables assessed onsite were total coliforms and E.coli as indicators of fecal contamination.

For the biological indicators, samples of benthic macro invertebrates were taken using a kicknet sampler as indicators of pollution in the sampled sites.

2.3 Agronomic assessment from field survey

Focus group discussions

Focus group discussions were conducted at five meetings with water use groups at sites listed in the table below:

Table 1. Composition of water user group members by gender

Water user group(s)	Total number engaged	Female (No.)	Males (No.)
Nyangorongo - Isule water user group	91	38	53
Bikone - Kyanya water user group	65	34	31
Rwankingi – Mubuku/ Muhambo - Katookye water user groups	99	23	76
Mubuku Integrated Farmers Association water user group	80	29	51
Kilembe/Mburakasaka/Kibandama/Kyanjuki water users group	100	44	56

The consultant team interacted with the community members on a number of issues using a check list. In particular, the interaction sought to understand status and trends with respect to biophysical capitals that have impacts on productivity, degradation and therefore probable effect on continued pressure on natural resources and habitats. In particular, discussions included questions on land use types and patterns, livelihood activities and farm/productivity practices. Information was also sought on trends of degradation with respect to soils, water and vegetation. Challenges to productivity of farming systems and farm or landscape wide interventions already adopted in the area were also documented.

Farm analysis

In order to validate information gathered from interactions with community members in water user groups, farm analysis was conducted in communities along the Nyamwamba, Sebwe and Mubuku catchments. Analysis/observations were conducted along transects perpendicular to the rivers at 100 meter intervals, measured with a tape measure up to a distance of 1km (1000m) away from the river. The locations of the transects are indicated below (see Figure 6).
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Table 2. Transect locations for the agronomic survey

Sn	Zone	Village
1	Nyamwamba upper	Kyanjuki/ Masule A
2	Nyamwanba Mid	Masule B
3	Nyamwanba lower	Road barrier Kasungu
4	Sebwe upper	Katumba Kisamba II
5	Sebwe/Nyabyayi	Kirongo/Kemihoko
6	Mubuku upper	Ruboni Bikone
7	Mubuku mid/Kitakena	Kyagabo
8	Mubuku lower	Izinga Kanyaminigo

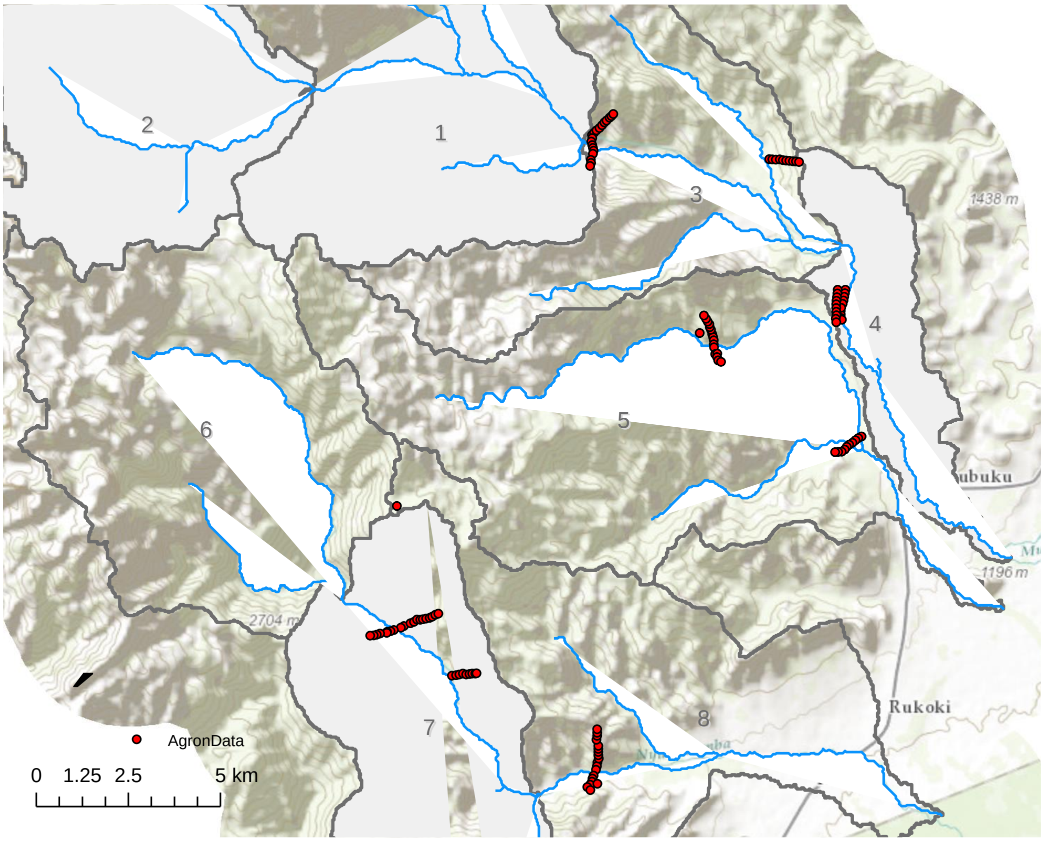

Figure 6. Map of transect locations and observation points

A tool was designed to record observations on a 20mx10m plot. Information recorded included land use, vegetation types, management practices, challenges and any sustainable land management interventions. The different zones represented different intensities of human/farm action with the upper or upstream zones having less intensity and increasing as you move down towards areas of high density settlement and thus farm activity intensity.

Figure 7. Example of organic residues that are being burnt (Nyamwamba watershed)

2.4 Stakeholder analysis and consultation

Stakeholder analysis was done following the definition ‘‘any group of people, organised or unorganised, who share a common interest or stake in a particular issue or system’’ (Grimble and Wellard 1997:175), in this case the Mubuku-Nyamwamba sub-watershed. The stakeholders will included both the small and large scale users of the water, stewards of the watershed such as private land owners and government agencies responsible for protecting the watershed and management of water resources. Other stakeholders included government agencies such as local governments, directorate of water resources, National Environment Management Authority.

The documentation and discussions with a few key informants will allowed a preliminary listing of stakeholders. This way of obtaining a preliminary set of stakeholders may be viewed as a mix of the ‘‘focal group’’ and ‘‘reputational’’ approaches to stakeholder identification.

2.5 Land cover change based on satellite data

Forest clearing, forest degradation through human disturbance and the deterioration of land productivity due to unsustainable agricultural practices is a major problem in the Rwenzori Mountains area. Both in the protected area, as well as in the areas outside of the park, forest loss has resulted in degraded lands. Not only rapid forest loss threatens the biodiversity, but also the unsustainable agricultural practices on deforested lands often result in severe soil erosion and loss of soil fertility.

The effects of soil erosion go beyond the loss of fertile land. It has led to increased pollution and sedimentation in streams and rivers, clogging these waterways and causing declines in fish and other species. Degraded lands are also often less able to retain rainfall, which can intensify flooding. Sustainable land use is beneficial to land-dependent users (farmers, forestry) as well as to water-dependent industries (hydro-power, drinking water supply).

To study forest loss at watershed level, multi-temporal analysis of satellite imagery has been carried out. Different satellite platforms are available for this type of analysis. Key is to use data for sufficiently large period to be able to detect change, and with an adequate spatial resolution to monitor environmental change. The best platform for this analysis is the NASA Landsat mission.

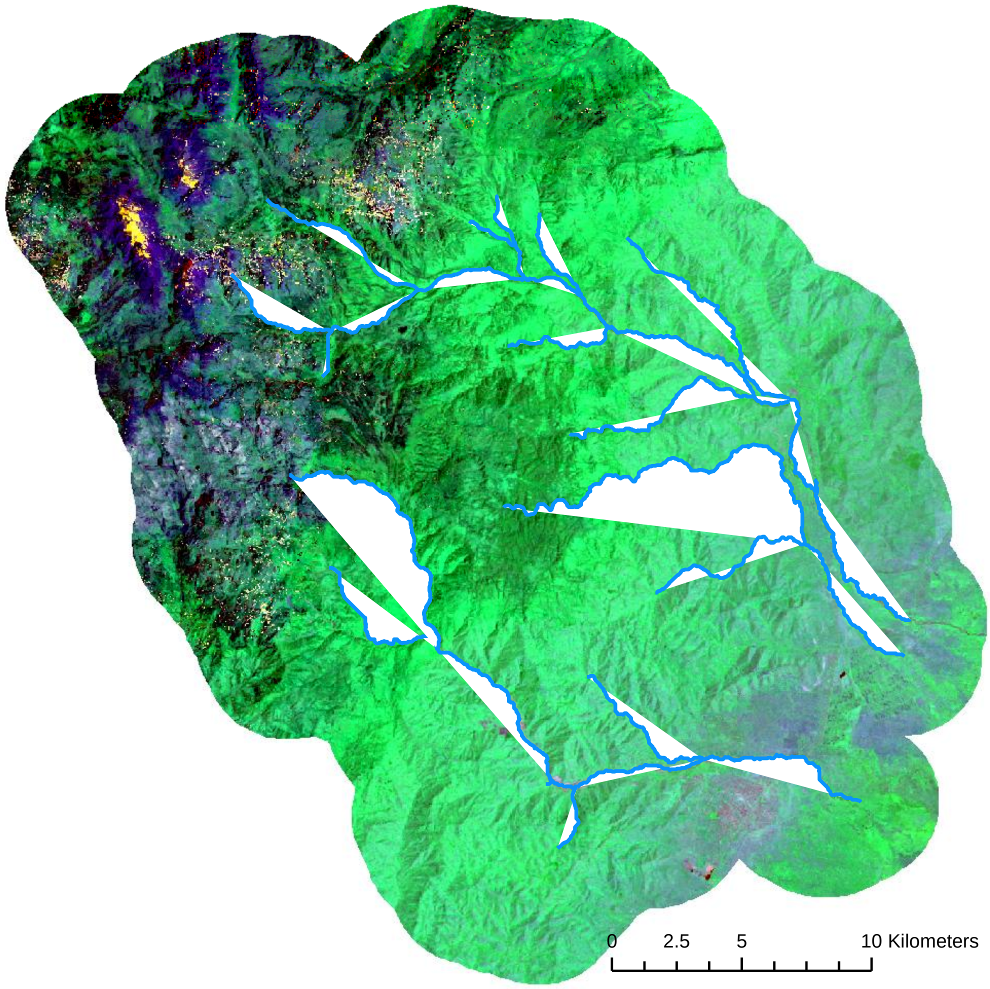

Figure 8. False color composite of Landsat (band 3, 4 and 5) of study area for year 2014

Recently, researchers released a global high-resolution map of forest cover loss [*Hansen et al.*, 2013]. This dataset can be considered as a scientific breakthrough as it is the first global dataset of this kind generated by a uniform and scientifically-based methodology. The dataset allows the comparison of land use changes among different regions. The dataset is annually updated at high-resolution of 30 by 30 meters, based on Landsat imagery. The latest update of gross forest cover loss includes the 2014 loss layer.

2.6 Water resources analysis and simulation

2.6.1 Public domain datasets for model input

The principal public domain datasets that were used for the water resources analysis are:

Digital Elevation Model. Elevation data was retrieved from the Shuttle Radar Topography Mission (SRTM) which is an international research effort that obtained digital elevation models on a near-global scale from to generate the a complete high-resolution digital topographic database of the Earth. The CGIAR-CSI version 4 provides the best global coverage full resolution SRTM dataset at 90m.

Rainfall data. For Africa, a reliable satellite-based rainfall dataset is available, called RFE, provided by the Famine Early Warning Systems Network (FEWS). The latest version is 2.0 (Xie et al. (1997)) and provides accurate daily rainfall estimates for Africa on a spatial resolution of 0.1° (~10 km), and is one of the best rainfall products available for Africa. RFE 2.0 estimates rainfall using a two part merging process; first all satellite data are combined using the maximum likelihood estimation, and secondly Global Telecommunication System (GTS) data are used to remove bias. For more information on the FEWS RFE algorithm, see the RFE 2.0 documents (http://www.cpc.ncep.noaa.gov/products/fews/rfe.shtml

Land cover. GlobCover2009[1] (GlobCover, 2011) product is used as land cover input for the model This land cover map is used because it is the most accurate map available (300 m resolution) for the study area currently. GlobCover is a European Space Agency (ESA) initiative which began in 2005 in partnership with several international organizations. The aim of that project was to develop a service capable of delivering global composites and land cover maps using as input observations from the 300 m MERIS sensor on board the ENVISAT satellite mission. The GlobCover 2009 land cover product is the second 300 m global land cover map produced from an automated classification of MERIS FR time series.

2.6.2 Model description

To understand upstream-downstream interactions and understand impacts to downstream potential beneficiaries of the PES scheme, a hydrologic simulation model is used. The aim of the water resources simulation tool is to capture impact of upstream changes on downstream water availability. Also the selected tool should be a well-proven and established model. For this preliminary phase, the tool can be setup using a simplified approach but should be able to gradually evolve into a more detailed analysis tool for follow-ups.

Based on the above requirements the WEAP model was selected. WEAP is a widely used water resources model that can be setup at different levels of complexity depending on resource and data availability. WEAP has been used for similar activities in many countries with similar challenges. Moreover, WEAP is relatively easy to use and often used in interactive stakeholder consultations.

The WEAP model was setup (Figure 9) to carry out this assessment. The WEAP model for the study area distinguishes

- Principal sub-basins
- Variability in precipitation
- Gradients in temperature
- Land cover distribution
- Slope distribution
- Water users

For this preliminary study, only historical streamflow is available from 1960-1985. This was used to perform an initial calibration of the model. This calibration can be further improved when more data come available during or after this preliminary study.

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[1] http://due.esrin.esa.int/globcover/LandCover2009/GLOBCOVER2009_Validation_Report_2.2.pdf

More details on model setup, parameters and calibration can be found in Annex II on model parameters.

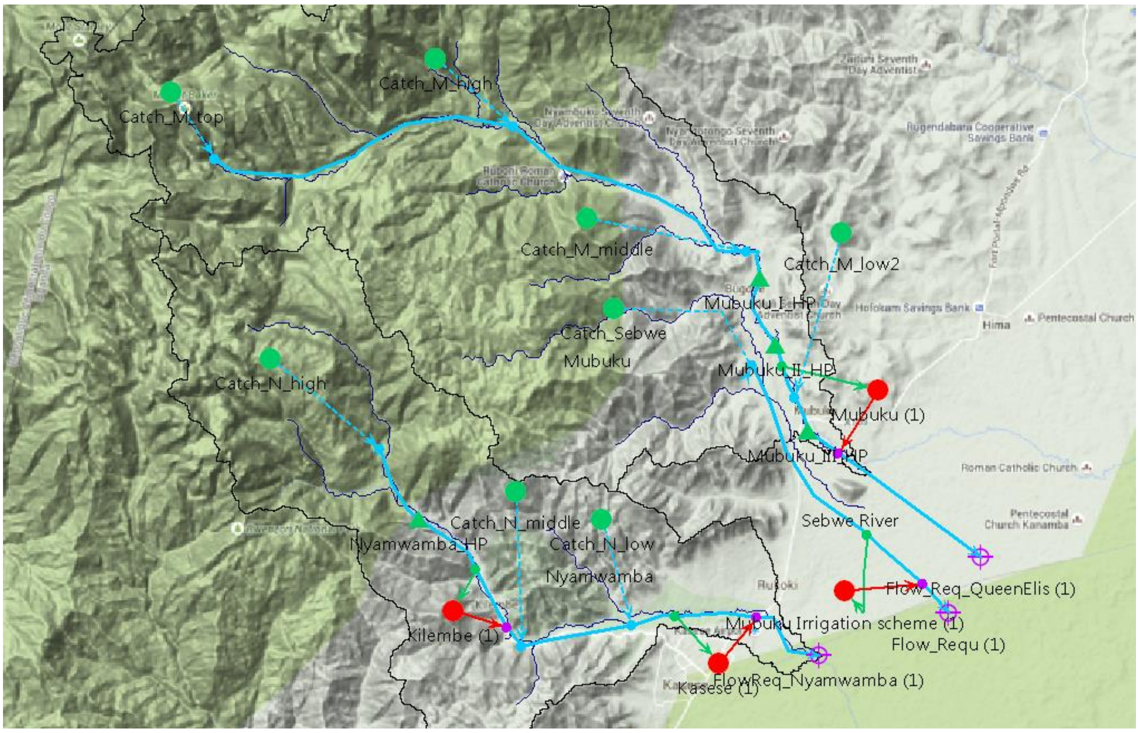

Figure 9. Setup of watershed simulation tool in WEAP. Green dots are catchments, red dots demand nodes, green triangles abstractions for hydropower.

2.6.3 Sediments

In many watersheds a statistically-significant correlation exists between suspended sediment concentrations (C) and flow rate (Q). This correlation between runoff discharge and suspended sediment load measurements is called the sediment rating curve and is in general rather accurate. Especially when detailed information lacks on sediment sources and land management patterns, this is the most common way to relate suspended sediment concentration with streamflow or storm runoff.

Sediment rating curves are generally expressed using a power-type regression equation:

$$C = a * Q^b$$

where C is observed sediment concentration (mg/l), a and b are coefficients, and Q is streamflow (m3/s) or storm runoff.

The coefficients of this equation depend on watershed characteristics, the erosion severity, or the availability of sediment in a certain area, the power of the river to erode and transport the available material, and on the extent to which new sediment sources become available in weather conditions that cause high discharge. Generally, the erodibility of the soils is attributed to the a-coefficient of the above equation. High values of the a-coefficient occur in areas characterized by intensively weathered materials, which can easily be eroded and transported. The b-coefficient represents the erosive power of the river, with large values being indicative for rivers with a strong increase in erosive power and in sediment transport capacity when discharge increases.

To generate a sediment rating curve and perform a regression analysis to calibrate the coefficients, data is necessary of at least an entire season. For this preliminary study, suspended sediment concentrations were only available for one moment in time, for different points in the watershed. Thus, there are not sufficient points to establish a regression with two unknown coefficients.

Given the extreme orography and turbulent flows in the watersheds, for this preliminary study it was assumed that a power of 0.4 in this equation is appropriate for the upper limit of sediment concentration (transport limit) using the kinematic flow approximation [*Ciesiolka et al.*, 1995]. Then coefficient *a* is estimated using the limited number of observations.

A useful method to study how sediment concentrations can be influenced by upstream changes in the watershed (for example by investing in sustainable land management) is using Duration Curves. The most widely applied type of duration curve is the flow duration curve (FDC). A flow duration curve is a plot of the percent of time that flow rates are exceeded. It removes information on the sequence of flows.

Concentration-duration curves (CDCs) show the concentration of a given water-quality constituent (e.g., copper, sediment) for each corresponding point on a FDC. The shape and utility of the CDC depends on the relationship between the constituent concentration and stream flow. When flow is multiplied by concentration to calculate the load for a given constituent, the resulting data may also be plotted as a load duration curve.

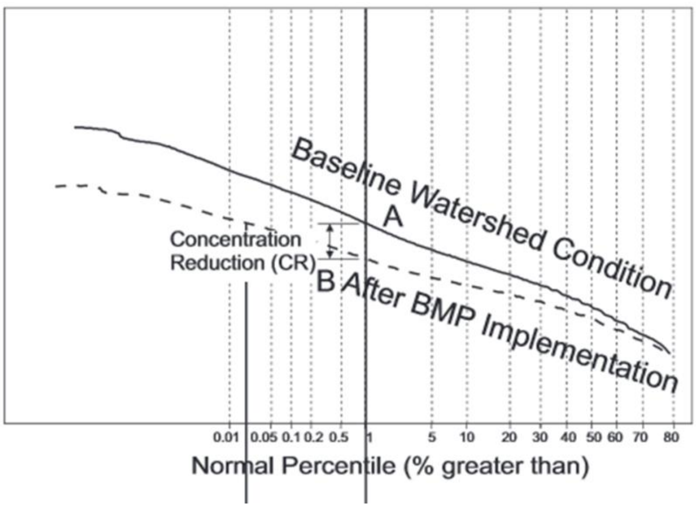

Figure 10. Example of sediment concentration duration curve that shows impact of taking measures compared to a baseline condition (source: [*Morrison and Bonta*, 2008]**)**

More detailed erosion-sediment modeling can be carried out using models that account for spatial variability of sediment sources and management practices. The Soil Water Assessment Tool (SWAT) is often used for this purpose [*Hunink and Droogers*, 2015], which includes the Modified USLE equation (MUSLE) for erosion and sediment yield calculation. This equation applied within a hydrological modeling tool like SWAT or SPHY [*Hunink et al.*, 2015], can take away some of the drawbacks of the sediment rating curve, like the limited representation of the effect of extreme events and the large variation in suspended sediment concentrations that can be found for the same discharge due to the seasonal dynamics in vegetation cover and soil moisture upstream (hysteresis effects).

2.6.4 Measures and implementation levels

The WEAP model is setup for a baseline scenario based on the best available data and by performing a first-order calibration with historic streamflow data. Then, a set of measures are being studied using the model, and compared to the baseline scenario to asses relative impacts:

- **Terracing** measures. By reducing the effective slope of land, terracing can reduce erosion and surface run-off by slowing rainwater to a non-erosive velocity. This can also increase infiltration rates, soil moisture and groundwater recharge. There are many terracing options available – the selection depends on soil, land cover, crop type and slopes.
- **Mulching** measures. Mulching has the advantage of providing additional protective cover at a time when crop cover is low. It improves infiltration, and may also beneficially reduce soil temperature. There are different types of mulching practices and materials used for mulching.
- **Agroforestry** measures. Group of measures that combine agricultural and forestry technologies to create more diverse, productive, and sustainable land-use systems. Trees or shrubs are grown around or among crops or pastureland.

Figure 11. Example of a terraced slope in the Rwenzori study area

These measures are explored using the model, and changes in flows are compared to the baseline situation. Given data limitations, the focus lies on relative changes. For precise estimates of absolute changes, more data is needed on the watershed and flows.

The simulations were done with different implementation levels (2.5%, 5%, 10%, 25% and 50%) to understand the impact of the scale of implementation. For each sub-basin the slope histogram was extracted, and it was assumed that priority is given to the steepest slopes (so 5% implementation of terracing means that in each sub-basin, the 5% steepest slopes are selected). Table 3 shows the corresponding area of intervention in hectares for each of the implementation level scenarios.

Table 3. Area of intervention for each of the scenarios (ha), assuming steepest slopes are given priority

Watershed	Total agricultural area (ha)	Intervention area for each scenario (ha)				
		2%	5%	10%	25%	50%
Nyamwamba	12444	249	622	1244	3111	6222
Sebwe	7093	142	355	709	1773	3547
Mubuku	12121	242	606	1212	3030	6060

Figure 12. Example of mulch that is being dried before its application on the land (Nyamwamba watershed)

3 Results

3.1 Hydrological Field Data

Discharge measurements

Flow measurements were measured (Figure 14) as an indicator of the amount of water available in the watershed but also to give an indication of how much is being diverted for the various uses.

Discharge on River Nyamwamba varied from 1.654 m^3/s at the site above the railway bridge to 4.38m^3/s at the Masule foot bridge. River Mubuku had the highest discharge values ranging from 2.35 to 10.55 m3/s at the point above the Bugoye dam. Discharge could have been much higher especially at Buraro Bridge inside the park but measurements were estimated because of the rough water.

Figure 13. Measuring water flow in river Nyamwamba. The process was collaborative with UWA and DWRM

For the sites with hydropower dams flows were measured both above above below the weirs to gauge how much was being diverted from the systems. River Sebwe discharge varied from 0.384m3/s at the point below the irrigation dams to 1.654m3/s at the site near the park boundary.

Environmental flows

Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater ecosystems and the human livelihoods and well being that depend on these ecosystems. On river Mubuku flows were measured before and after diversion of water for hydropower generation for Bugoye Power Ltd. Above the weir, flow was 10.5m^3/s while below the wier it reduced to 0.6m^3/s. The analysis showed that the water that remained in the river was less than 10%, a value recommended as environmental flows. An analysis was also made on River Sebwe before and after the dam for the Mubuku Irrigation Scheme. The flows were 1.5

and 0.4 m³/s respectively indicating that the volume left in the stream was slightly higher that the recommended 10%(0.15m³/s).

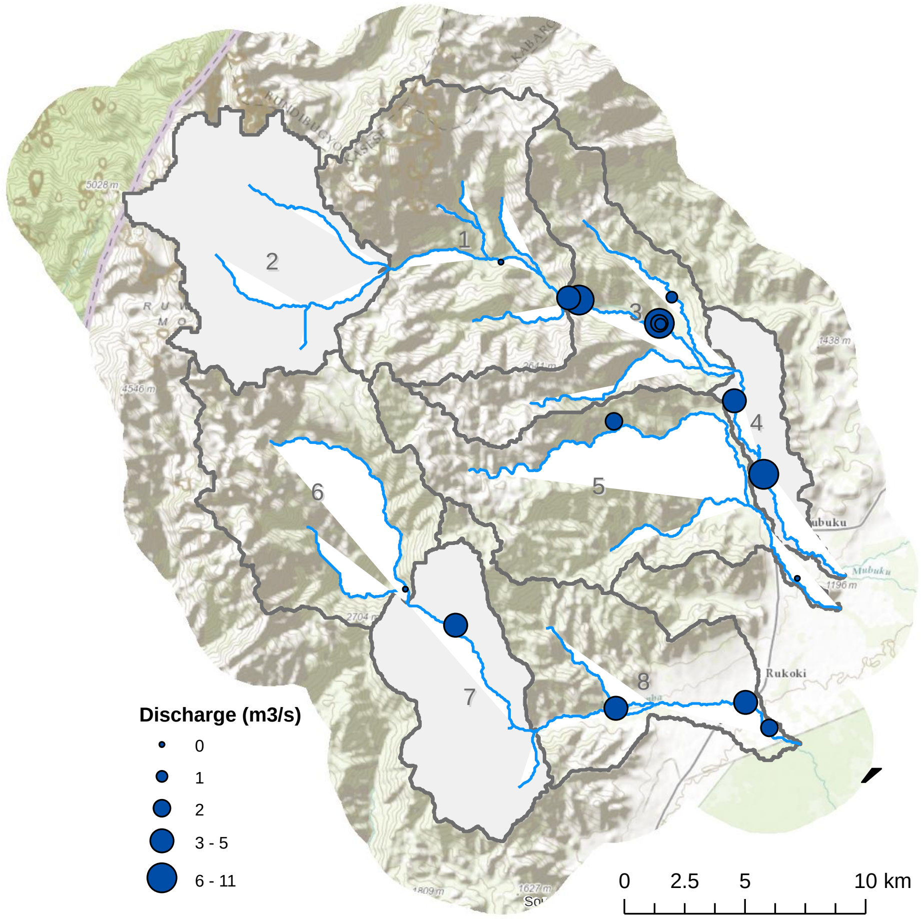

Figure 14. Map of measured flow rates at the different locations

Water quality variation

The pH on River Nyamwamba and its tributary Mulyambuli stream was generally neutral and it ranged from 6.84 to 7.79. Temperature varied along an altitudinal gradient being lower inside the protected area system while it was highest at the downstream site at the Railway bridge.

Turbidity is one of the key water quality measurements that were measured on-site, and are represented in a map in Figure 15. Turbidity along river Nyamwamba was lowest at Masule bridge (7.2 NTU) and increased progressively downstream up to 98.5 NTU at the railway bridge site. The results show that a rapid increase in turbidity may be due to human activities downstream such as sand mining and stone quarrying.

Dissolved oxygen was quite saturated at most sampled sites but was lowest at the site near Kiwa hotsprings which could be an indication of organic pollution from the settlements in Kilembe mines and hospital establishments.

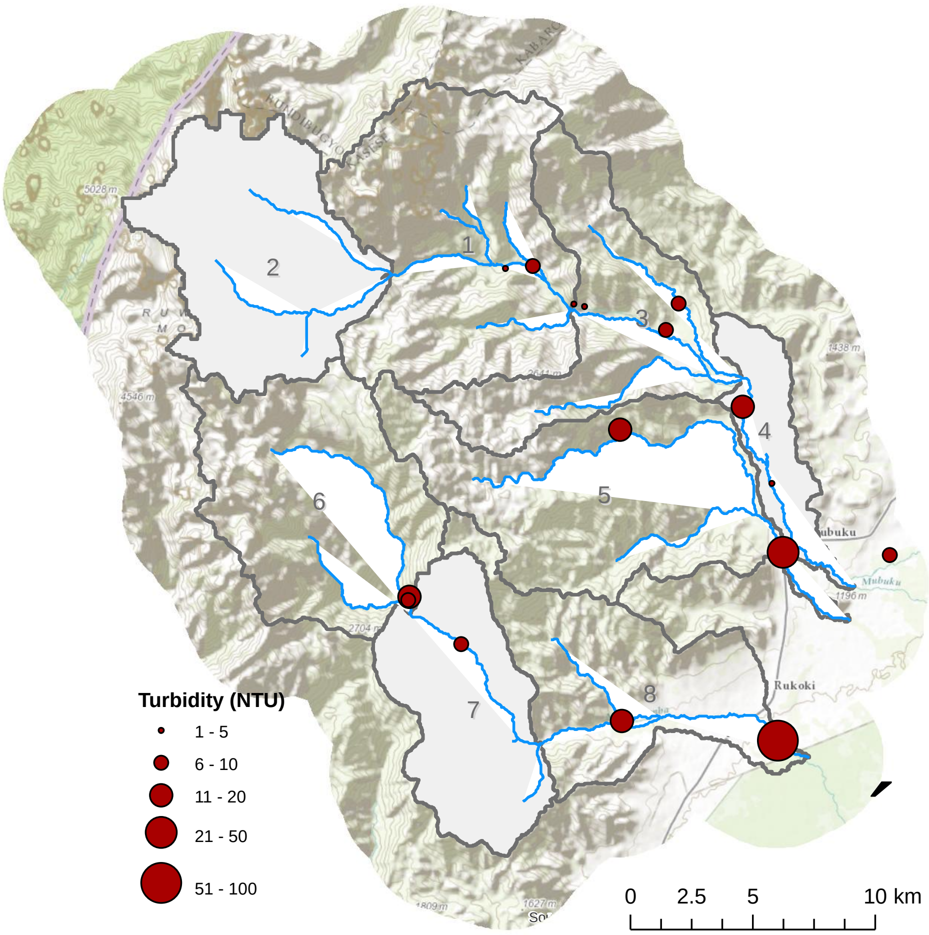

Figure 15. Map of turbidity values that were measured at the different locations

Total coliforms and E.coli counts along Nyamwamba river increased downstream but the total coliforms were highest at the Kiwa hotsprings site at 5422 counts. All the water sites had total coliforms and E.coli above the national standard for portable water of 0. The fecal coliforms were mostly high near human settlements and could be an indication of poor sanitation facilities within the Nyamwamba watershed. Fecal contamination was also abnormally high in the small tributaries of Mulyambuli and Kyoho inside the park. This may pause a health risk to the rangers and porters who usually drink water from the streams.

In Mubuku river pH was generally neutral across all sites ranging from 7.87 to 7.84. Electrical conductivity ranged from 41 to 80 and it increased along a downstream gradient. Turbidity within the Mubuku catchment was generally low ranging from 0.7 to 10.5NTU. The low turbidity may be explained by the clearly water and the fact that it never rained during the sampling times.

Dissolved oxygen was quite high across the sampled sites but would generally decreased downstream with increase in water temperature and possibly an increase in organic matter. The ORP ranged between 233 and 290 mV along the Mubuku river system. Fecal contamination in form of total coliforms varied from 26 inside the forest to 562 below the KCCL power plant. E.coli on the thoer hand varied from 7 inside the park to 430 in Kithakena stream. This indicated that the watershed drained by the stream has poor sanitation facilities and the population may be prone to waterborne diseases.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand were analyzed for samples collected. BOD ranged from 0.15 mg/l at Mubuku river inside the park to 0.95mg/l at Mubuku downstream. The variation in BOD shows a progressive increase in organic matter downstream as the sources of pollution increase especially from diffuse sources such as human settlements, and point sources such as the Mubuku Prison Farm. COD was generally less than 20mg/l across all the sampled sites indicating negligible levels of organic pollution.

Biodiversity indicators

Family richness of aquatic insects sampled varied from 0 at Nyamwamba above railway bridge site to 14 at Sebwe river below the park boundary. Generally the diversity of aquatic insects was high in relatively pristine sites inside the park compared to sites outside the park. Highly sensitive taxa of Mayflies, Stoneflies, and Cadisflies (Ephemeroptera, Plecoptera and Trichoptera orders respectively) dominated the in-forest sites.(Appendix…)

Fish biodiversity was assessed at several sites in the project area. Fish species richness ranged from zero at two sites inside the park to nine species in Nyamwamba above the railway bridge. The fish assemblage was dominated by hardy species such as *Barbus neumayeri* and B. apleurogramma. A relatively sensitive Albertine Rift endemic species (Varicorhinus ruwenzorii) previously documented in the Mubuku river was not recorded during this survey. Another introduced species, the Brown Trout (*Oncorhynchus mykiss)* previously recorded at the Mubuku-Bujuku confluence was also not recorded downstream. Another Albertine rift endemic species *Platypanchax modestus* (Ruwenzori lampeye) was recorded in Nyamwamba and Sebwe rivers.

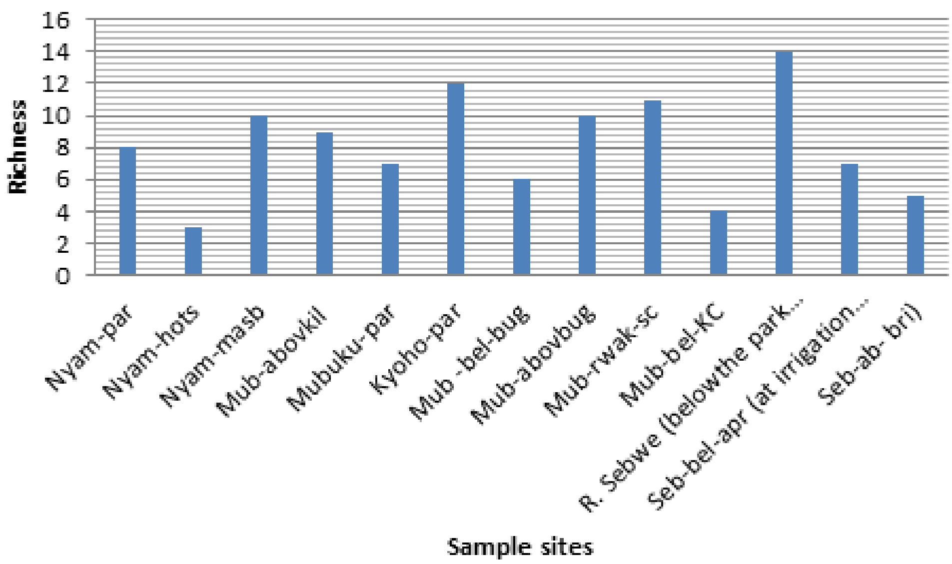

Figure 16. Variation in family richness of aquatic insects at the sampled sites. High richness indicates pristine or un- degraded conditions.

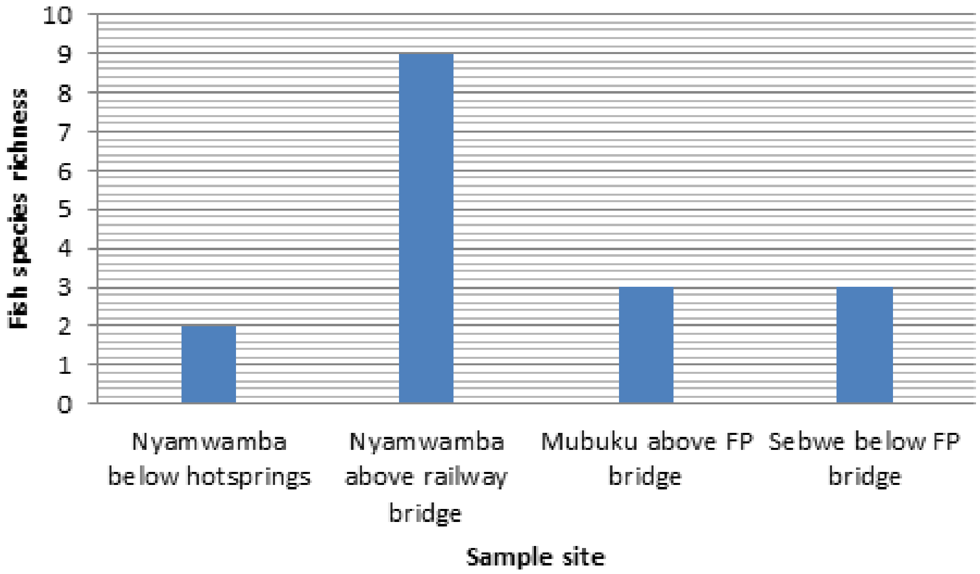

Figure 17. Variation in fish species richness in the sampled sites

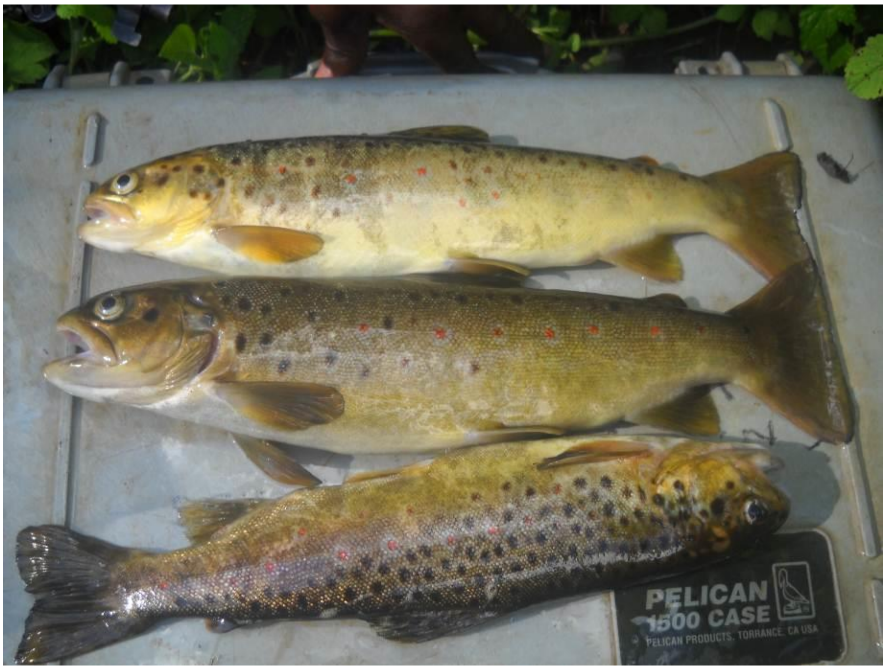

Figure 18. *Oncorhynchus mykiss* caught at the confluence of Bujuku and Mubuku rivers

Figure 19. *Varicorhinus ruwenzorii*: An Albertine Rift endemic recorded only in Uganda.

3.2 Agronomic assessment

3.2.1 Field survey

Livelihoods

Majority community members in study area derive livelihoods from crop farming, and limited livestock integration. There are however limited nonfarm activities including brick making, local produce trade and formal employment. Farming is conducted on small fragmented pieces of land estimated at an average of 0.2 – 1.2 acres per household according to the Kasese District Poverty profiling and mapping study of 2012. A detailed analysis of livelihoods will be covered in a different study.

Land use

Results from field plot analysis show that the area is heavily utilized for crop farming with only 7% retaining natural systems. The largest area representing 52% of the assessed area is under intercrops involving at least one perennial crop (see Figure 20).

Permanent crops are important in providing permanent vegetation cover and thus could be major components in PES scheme. This can however be improved with complimentary components that emphasize reducing other degradation forms especially combating soil and water loss by erosion.

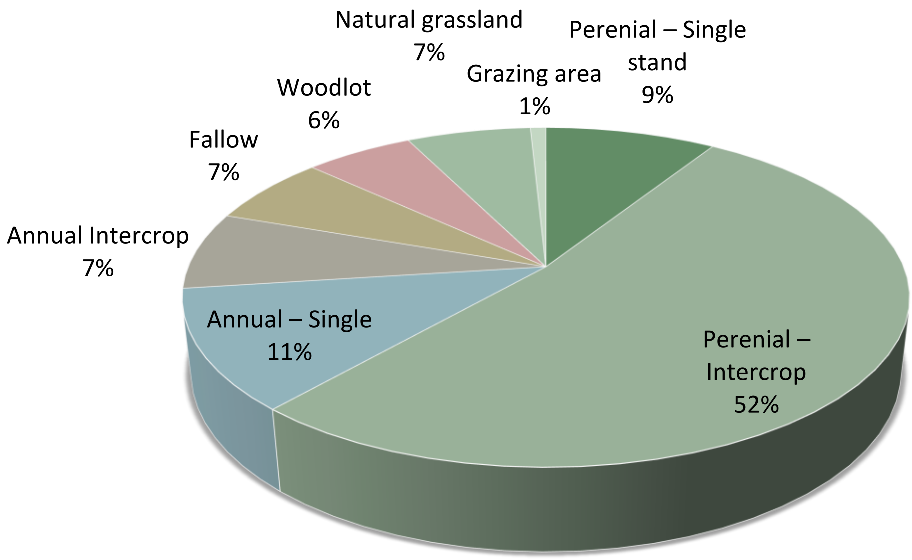

Figure 20. Land use types according to agronomic survey

The farming system is majorly an integration of coffee as the major cash crop with banana, cassava and beans as major food crops. Coffee is the most popular crop appearing on 24% of all plots assessed. Therefore, any interventions to improve sustainable land management must take into account this farming system and preference of these commodities. Coffee is one of the nationally preferred cash commodities due to its potential to improve/create wealth at household level, in addition coffee has a consistent international market and has been the biggest foreign exchange earner for Uganda.

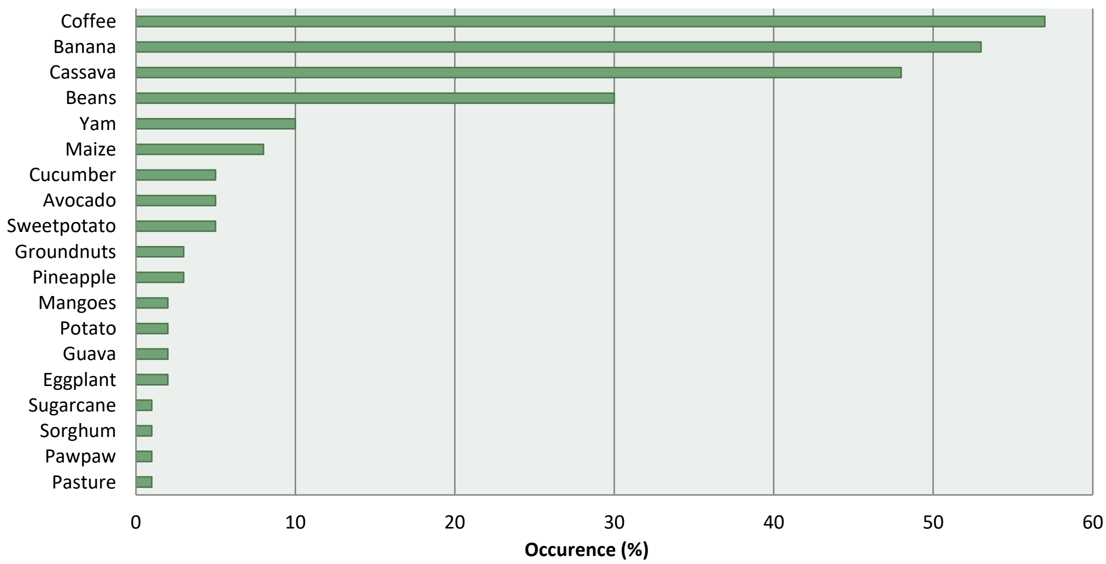

Figure 21. Major crop commodities according to agronomic survey

For farmers to obtain maximum benefit from their effort, it's imperative that they apply good management practices including good agronomy. However, there were minimal deliberate efforts to practice good agronomy. Practices like weed control, spacing, intercropping were observed but there wasn't any evidence of deliberate efforts.

Challenges

One of the major challenges observed on plots visited was the evidence of land degradation. On 83% of plots assessed, some form of erosion was observed, including landslides in the catchment. This is escalated by the fact that most of the terrain is very steep, steep or strong to moderate slope, and there are visible signs of over cultivation and declined fertility..

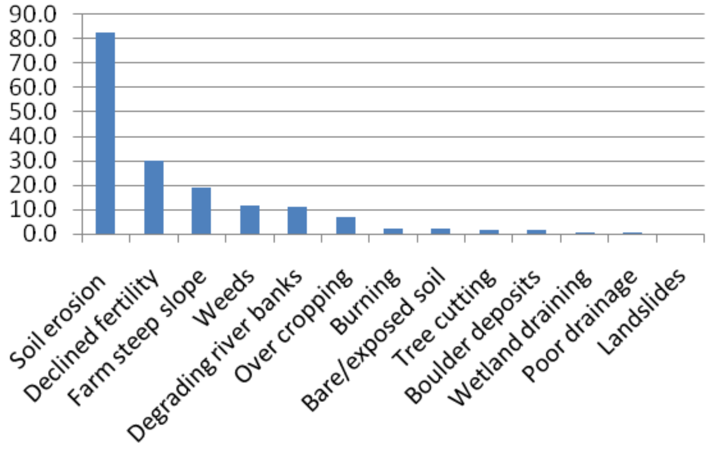

Figure 22. Degradation types on percentage of plots

While there is some legislation restricting cultivation of such slopes, this has been overlooked and the consequences in terms of degradation are evident. Communities also noted that cultivation of marginal lands especially on very steep slopes was responsible for the widespread erosion. They also note that due to high population density, and limited land holdings. They don't seem to see a solution and will keep cultivating the area. Due to high demand for fuel charcoal, communities also identified tree cutting as an area that need interventions.

There are a number of government and non government actors that have initiated interventions in the areas to halt and reverse degradation in the area and improve livelihoods, these include government extension staff, civil society organizations and nongovernmental organizations. These however are still isolated covering just a very small percentage of the community and offer services in soil and water conservation, financial services, livelihoods improvement and other sustainable land management practices. From the farm assessment results, adoption of sustainable land management practices is still very low with small percentage of farms implementing the practices.

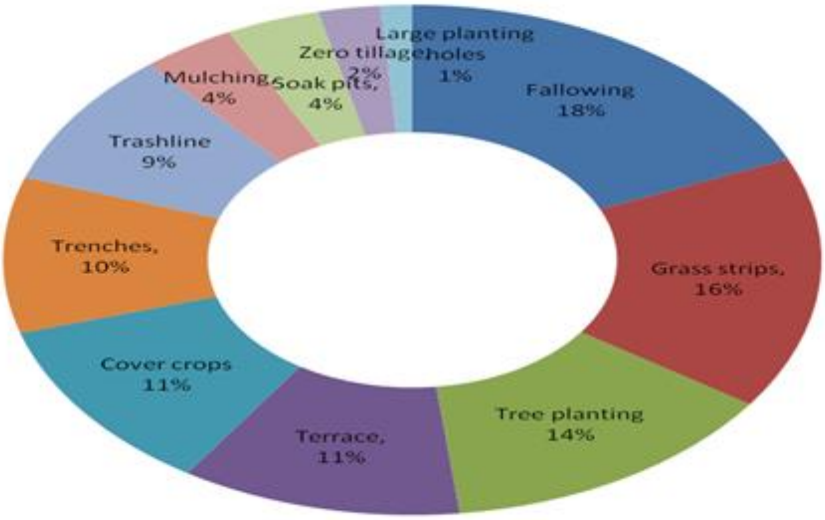

Figure 23. Percentage of farms that adopt different SLM technologies

There is also evidence of pests and diseases in most of the assessed plots. Banana bacterial wilt is one of the single major constraints with potential of causing 100% yield loss. While there were less incidences on ground, there was evidence of its impact with previous efforts probably having reduced its incidence. There is however high incidence of Coffee leaf rust and cassava mosaic disease. Cassava mosaic disease should interest district and other stakeholders because it spreads rapidly by insect vectors and has potential of wiping the entire cassava population. Other observed pests and diseases are indicated in chart below.

Other major challenges identified include limited tree coverage and over-cultivation due to small land holdings. This, added to the high erosion levels that cause loss of fertile soil, a key constraint mentioned by 22% of the farmers is mineral deficiency (see Figure 24). Unsustainable land management and erosion cause fertile lands to degrade and reduce the production potential of the soils.

The team also noted proliferation of *Lantana camara*, an invasive thrub that is threatening species diversity due to its competitive nature. While it has already been recognized as a major threat in grazing areas, there is evidence that it has spread to farming areas and is negatively affecting quality of fallow and thus contributing to degradation.

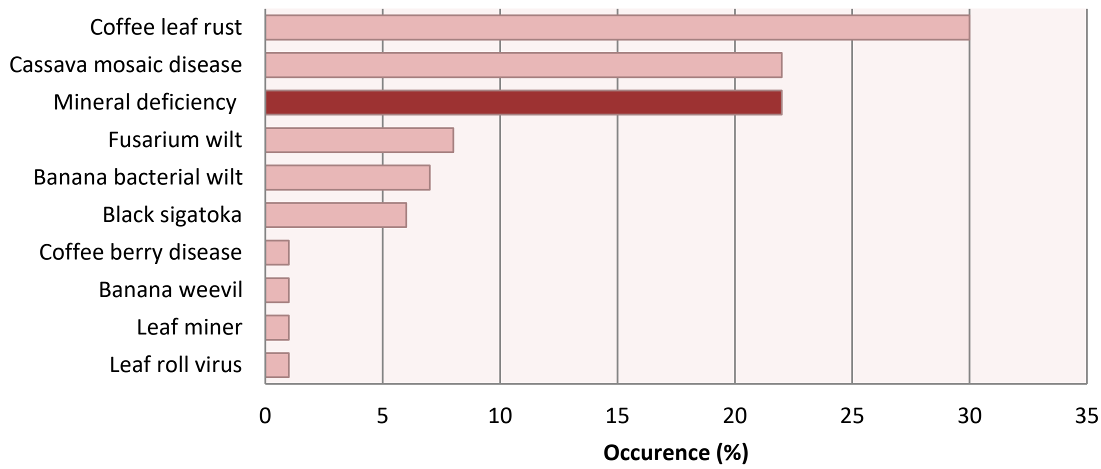

Figure 24. Reported principal constraints on production according to farmers

Based on the agronomic survey, it has become clear that there is some evidence of currently implemented sustainable land management (SLM) practices but still very scattered and limited (Figure 23). Trench terracing, one of the most trusted technology in soil and water conservation was only observed on 10% of the assessed plots while the most popular technology: grass strips, was observed on only 16% 0f the plots. Upscaling these practices and enabling the uptake by a larger group of farmers is therefore a clear opportunity for the PES scheme in these watersheds.

3.2.2 Recommended interventions

Land degradation caused by farm activity upstream not only causes reduced productivity but also has consequences to users downstream through reduction in flow volumes and siltation which affects water quality. It is important therefore to design a system through negotiation that compels water users to invest in a PES system to improve sustainable land management activities upstream.

PES may be delivered in form of supporting farmer investments and other in kind incentives like training, inputs, equipment which will improve upstream income generation that will in turn motivate and provide incentive for further sustainable management activities. There has been reported evidence that implementation of recommended sustainable land management practices has been able to improve yields three fold per unit area, a significant incentive for farmers.

The interventions below may be considered as components of PES in upstream communities to reduce sediments and siltation as well as improve productivity of the farming systems. Such interventions will potentially improve on the human, social and natural capital assets required to improve sustainable livelihoods and reduce vulnerability to environmental shocks, while the social and financial capital assets will follow automatically. The following interventions are recommended:

i. Promotion and scaling up of sustainable land management (SLM) interventions, these may include *fanya chini* or *fanya juu* trenches, grass strips, soak pits, mulching, zero tillage practices. This may be delivered by adopting a farmer participatory learning approach like a farmer field school (FFS). FFS is a participatory method for technology development and dissemination that gives farmers the opportunity to make informed decisions about farming practices and commodity adoption through discovery based learning. The school, which consists of 25 – 30 farmers in a selected locality, is facilitated to discover solutions to prevailing constraints and challenges. FFS bring together farmers in a learning situation to undergo a participatory and practical season long training on a given topic. The FFS process provides a learning environment that helps build the capacity and leadership skills of the group. The FFS goes ahead of mere agricultural practice and also addresses other livelihood related issues. The FFS is conducted for the purpose of helping farmers to master and apply specific management skills and emphasis is on empowering farmers to implement their decisions in their fields. The FFS also improves on community cohesion and ownership. The community can also be motivated with items like tools to motivate them.

ii. Landscape vegetation restoration programs: It was noted that due to intensity of cultivation, there has been widespread tree cutting and conversion of ecosystems leaving most of the land in the landscapes bare. In addition, there was evidently widespread river bank erosion with most areas lacking protection. It's therefore recommended that tree planting on bare areas as well as river bank tree planting be implemented to improve vegetation cover and protect river banks.

iii. Energy efficient/energy saving technologies: It was noted that a lot of trees have been cut for fuel wood and for burning charcoal to sell to neighboring Kasese town. While there are alternative sources of energy, the economic status of communities imply that they will not afford then in the short run. Therefore, there is need to promote affordable energy saving technologies like improved stoves, briquettes and biogas.

iv. Fertility improvement and other productivity enhancing technologies; It has been documented that poverty is one of the factors that exert pressure on natural resources, with the poor heavily reliant on natural resources to derive livelihoods and survival. Imported incomes through improved productivity per unit area provides alternative livelihoods and reduces the pressure on natural ecosystems. Against this, it is recommended that the PES scheme supports activities that improve farm productivity and provide options for income enhancement at household level. This may include integration of livestock (for example small ruminants). Livestock improves and optimizes local nutrient and biomass cycles, where fodder crops and stovers are fed to livestock while animal dung can be used to improve crop productivity. Other practices may include composting and other fertility enhancing technologies and elite varieties.

v. Training, capacity building and empowerment for women, school children and other interest groups. Women are the major actors in the farming systems and domestic activities including energy consumption. Programs that improve women and children awareness will improve their knowledge base and skill in adopting and practicing best farm management interventions and energy efficient technologies. Focus should also be put on developing community institutions to enable utilizing local capacities in management, monitoring and evaluation and community policing of local legislation (community byelaws and other legal instruments)

Implementation of these recommendations will translate into desired outcomes, including increased coverage of recommended practices (length, acreage), reduced erosion, improved vegetation cover, changes (reduction) in energy use at household level and improved productivity of family farms leading to improved quality of life, this will compliment the improved water quality and other ecosystem services. In order to achieve this, the activities below are recommended.

Table 4. Recommended technologies and interventions on upstream farms

Sn	Technology/intervention	Unit of measure
1	Establishment of grass for stream bank protection	meters
2	Establishment of trees and shrubs for stream bank protection	seedlings
3	Tree planting on boundaries	seedlings
4	Contour trenches (Fanya juu and Fanya Chini)	meters
5	Contour grass strips (Napier, Setaria and Kikuyu grass.)	meters
6	Mulching and management of crop residues	acres
7	Tree planting in compounds, home gardens and public places	seedlings
8	Establishment of grass for stabilization of soil and water conservation structures	meters
9	Establishment of trees/shrubs on soil and water conservation structures	seedlings
10	Establishment of grass in lines	meters
11	Establishment of Trees and shrubs in contour hedge rows	seedlings
12	Woodlot establishment	acres
13	Trash lines	meters
14	Tree planting on roads and paths	seedlings
15	Tree planting for wind breaks and shelter belts	seedlings
17	Contour bands	meters
18	Diversion bands and soak pits in crop gardens	meters
19	Protection of existing forests and trees	acres
20	Fodder Bank Establishment and management	acres
21	Infiltration basins	numbers
22	Organic manure (cowdung, compost etc)	acres
23	Improved cook stoves	numbers
24	House hold solar lumps	numbers
25	Fruit orchards	seedlings
26	Establishment of Bamboo	numbers
27	Beekeeping (hives)	numbers
28	Cover crops	acres
29	Improved furrow	acres
30	Check dam	numbers
31	Gully rehabilitation	numbers
32	Roof water harvesting facilities	numbers

3.3 Stakeholder Analysis

Several stakeholders within the Mubuku Nyamwamba watershed have been identified (see Figure 25). They can be categorized under three headings

a) Potential suppliers or sellers of watershed services: These include the local communities who are mostly organized in water user groups or associations but also include government agencies such as Uganda Wildlife Authority and National Forestry Authority who are stewards of watersheds in the landscape. Under this category, it is only the water user associations that have been interviewed or engaged during focus group discussions.

b) Potential buyers of watershed services: These include the private sector and government agencies who directly benefit from the water generated by the two watersheds. They include hydropower companies, utility companies such as National Water and Sewerage Corporation. Formal discussions/interviews are planned when the data from the assessment is synthesized and this will be performed under the socioeconomic study.

c) Partners/potential arbiters. These include government agencies such as the directorate of water resources, National Environment Management Authority who regulate the use of water resources in the country. Kasese District local Government and other NGOs within the watershed also belong to this category.

The potential roles of the identified stakeholders will be mapped when formal interviews and discussions are held with them. A detailed stakeholder analysis detailing their roles and responsibilities in the PWS scheme will be undertaken under the socioeconomic study.

Figure 25. View with main stakeholders and monitoring points (blue dots = flows, orange squares = water quality)

3.4 Water Resources Analysis

3.4.1 Sub-basin biophysical characteristics

Public domain datasets (see section 2.6.1) were analyzed and pre-processed to be used as input in the water resources model WEAP. Based on the digital elevation model, the channel network and sub-basins were delineated. Slope distribution was analyzed, rainfall variability was studied and land cover distribution per sub-basin was determined.

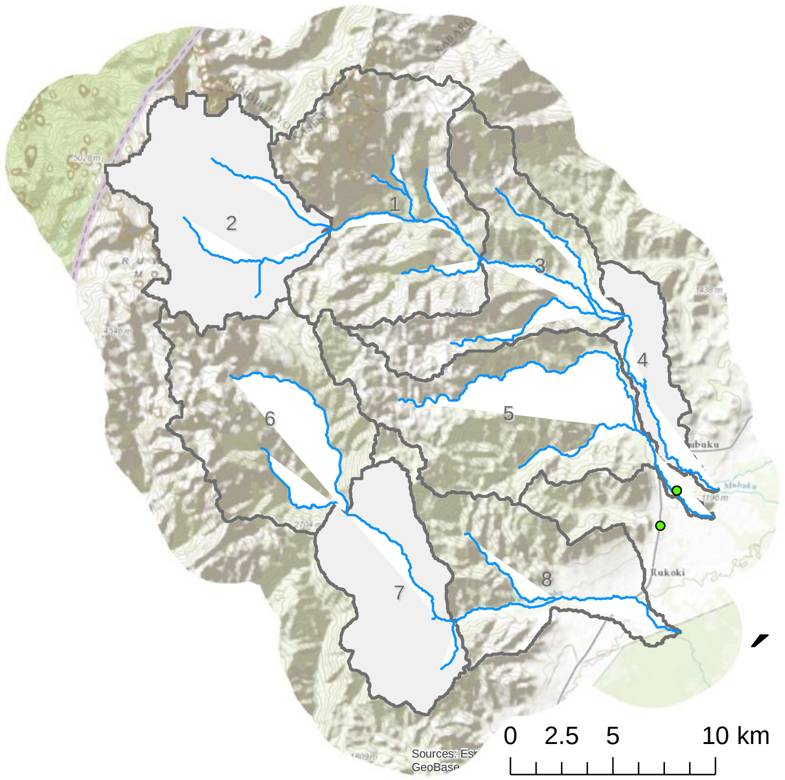

Figure 26. Sub-basins and drainage network as delimited from SRTM elevation model

Table 5 shows per sub-basin several key indicators that determine the hydrological characteristics of the watersheds.

Table 5. Main biophysical properties of delineated sub-basins.

Variable / sub-basin ID	1	2	3	4	5	6	7	8
Total area (km2)	97	85	63	22	90	80	55	65
Mean elevation (masl)	2768	3710	2070	1262	1950	3164	1782	1399
Mean annual precipitation (mm/yr)	2242	2889	1762	1207	1680	2513	1564	1301
Mean temperature (ºC)	14	8	18	23	19	11	20	22
Rainfed cropland (%)	47	3	83	91	79	26	94	81
Montane forest (%)	20	4	12	9	13	12	6	19
Heath moss forest (%)	27	52	5	0	8	45	0	0
Afroalpine zone (%)	7	41	0	0	0	18	0	0

Rainfall was obtained from the FEWS dataset for the cell that includes Kasese town. Local data for Kasese was received from DWRM and from the GSOD global dataset, but contained too many data gaps to be considered reliable. For this reason, the FEWS dataset was used. Rainfall totals correspond with literature values (on average around 900 mm per year, see Figure 27). For the mountainous parts of the study area where orographic rainfall is important, FEWS requires bias correction. For this reason, a lapse-rate approach was used to account for the large rainfall gradients depending on elevation. The lapse rate was based on [*Taylor et al.*, 2009] and assumed to be 0.7mm*m^{-1}.

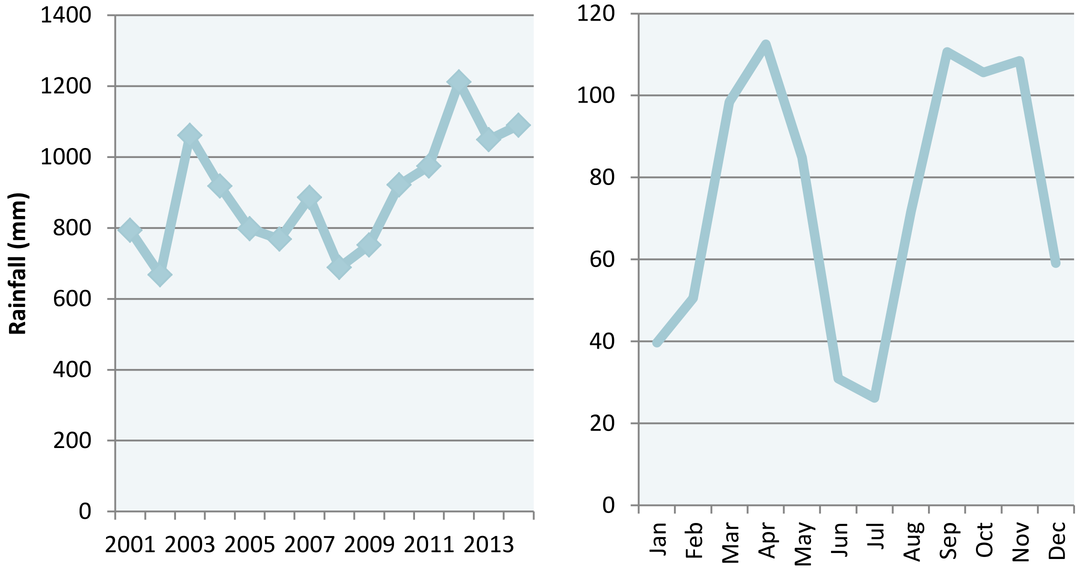

Figure 27. Annual and monthly rainfall for Kasese (source: FEWS)

For the protected area, the GlobCover dataset (Figure 28) does not distinguish gradients in main vegetation types that are elevation dependent. Therefore [*Taylor et al.*, 2009] was used to derive for each sub-basin the proportion of Montane forest, Heath moss forest and Afroalpine zone, as function of elevation.

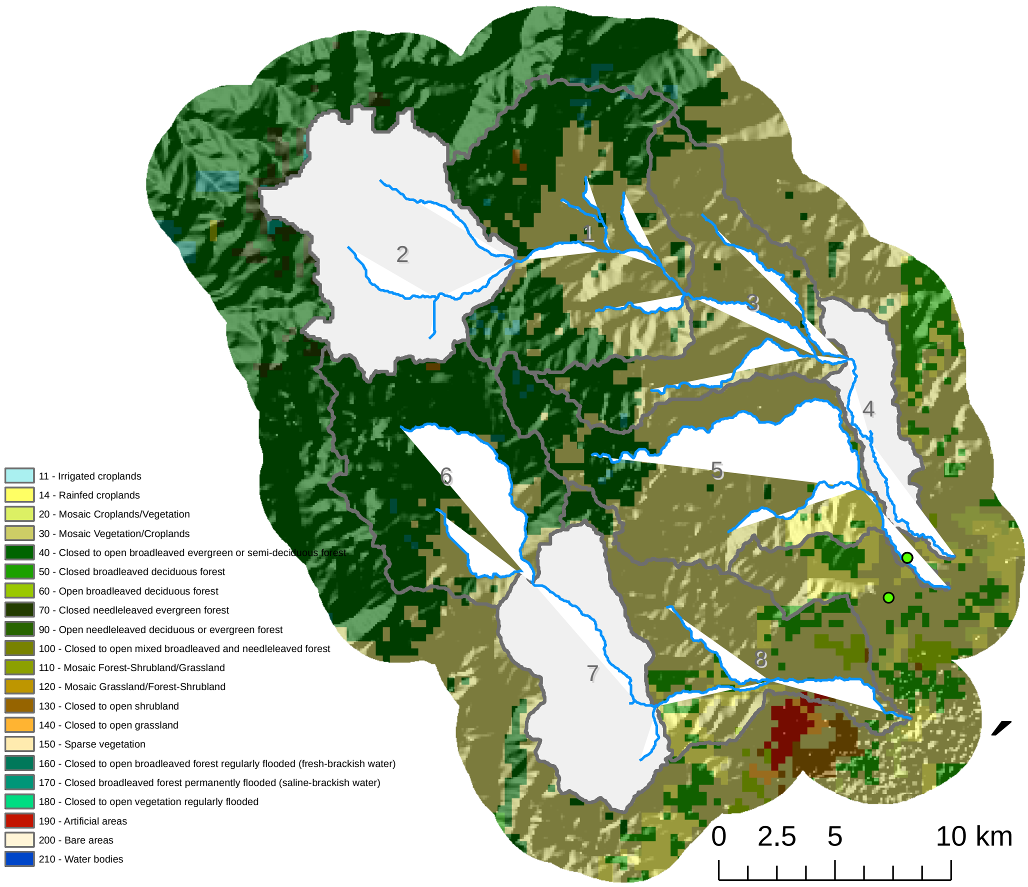

Figure 28. GlobCover land use dataset for study area

3.4.2 Flow duration analysis

Historical data on flows have been received from DWRM Entebbe. Although from many decades ago under a probably complete different situation in terms of land use, these data can provide insight in how the catchment response has changed since then due to land cover changes.

For the received data, baseflow separation was carried out using the "Local Minimum Method" [*Sloto and Crouse*, 1996]. This method takes the minimum values of the hydrograph within a pre-defined interval by following different criteria and connects them. The discharge under the constructed line is defined as base flow accordingly.

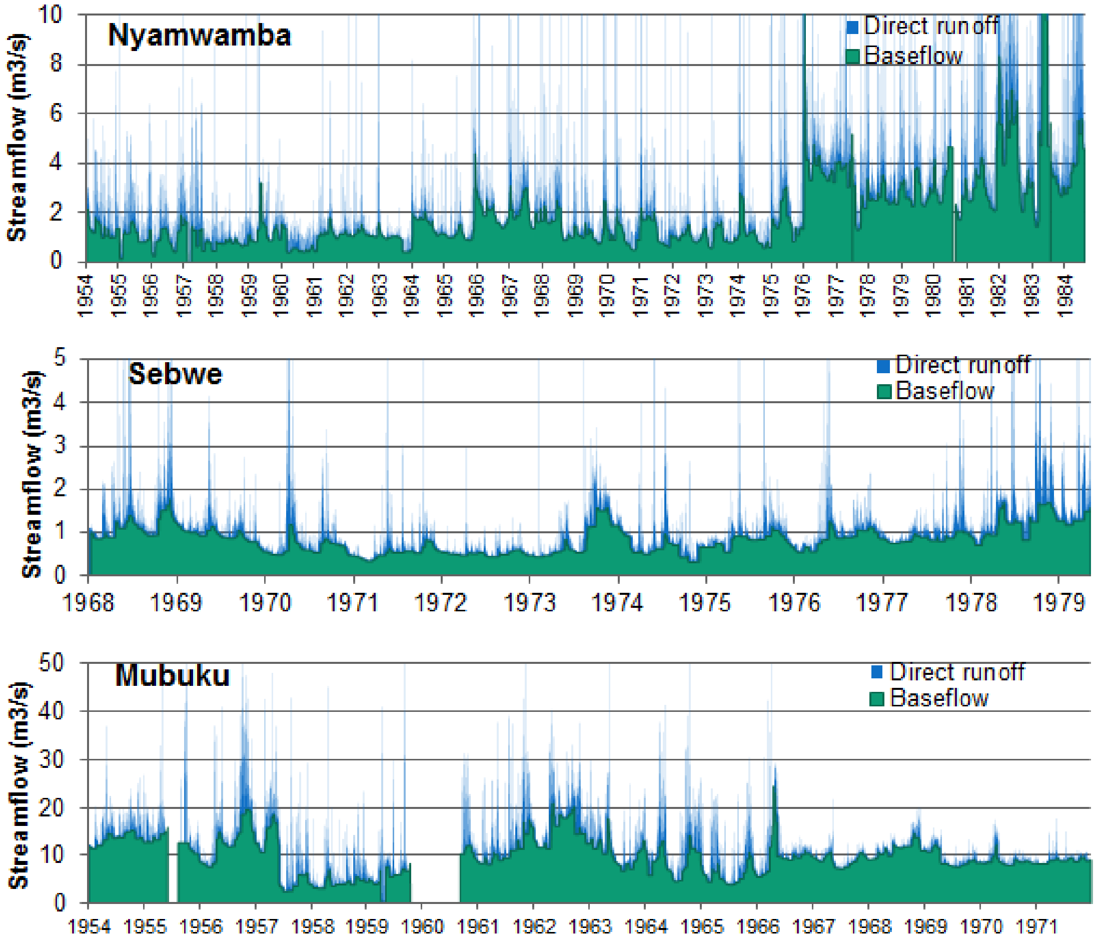

Figure 29. Hydrographs separated for direct runoff and baseflow from historical data 1950s to 1980s

Figure 29 shows the hydrographs of the 3 watersheds, separated for direct runoff and baseflow based on the historical dataset. As can be seen, for the Nyamwamba data an abrupt change in baseflow and streamflow is observed from 1976 onwards. This may be due to errors in data collection.

Table 6 shows key indicators extracted from the historical dataset. The baseflow component is relatively highest for the Mubuku watershed (70% according to this method). This can be attributed to the fact that a significant part of the water from this watershed comes from high mountainous areas including a small glacier.

Table 6. Streamflow indicators from historical dataset

Indicator (m^3/s)	Nyamwamba	Sebwe	Mubuku
Average flow	3.4	1.2	12.8
Average baseflow	1.8	0.8	9.0
Maximum observed flow	22.0	1.8	24.4
Percentile 80	2.7	1.0	12.4
Percentile 20	0.9	0.5	5.5
Baseflow / average flow	54%	68%	70%

Most likely, the baseflow component has changed since this period considerably, due to a combination of factors:

- Glacial retreat in Mubuku watershed (does not apply to Nyamwamba and Sebwe)
- Changes in land cover in the natural upstream areas
- Land conversion from natural to agriculture
- Agricultural practices

To be able to understand to what extent the flow regime has altered over the last decades, a flow measurement campaign should be carried out. To carry out hydrograph separation, streamflow data should be available for at least a 1-year period. A more reliable estimate can be obtained when data are available for several years, thus accounting for inter-annual climate variability. Unfortunately, data from the current measurement campaign are not sufficient to obtain estimates on baseflow. Even if measurements were taken in the dry period (which is not the case), errors in the estimate would be too large.

From the historical dataset, flow duration curves (FDC) were made. The FDC is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest. FDCs characterize a watershed's response to precipitation and other inputs, integrating multiple factors that affect stream flow at a point (topography, soil distribution, climate, land use, flow controls such as dams, etc.).
A flat FDC implies a greater level of storage in the basin and a steeper FDC implies a flashy watershed, where streamflow increases quickly following precipitation.

For the main watershed for hydropower use (Mubuku), Figure 30 shows the flow duration curve. Most likely, the current flow duration curve would show higher values on the left (high flow occur more often) and lower values on the right (low flows occur more often) of the plot.

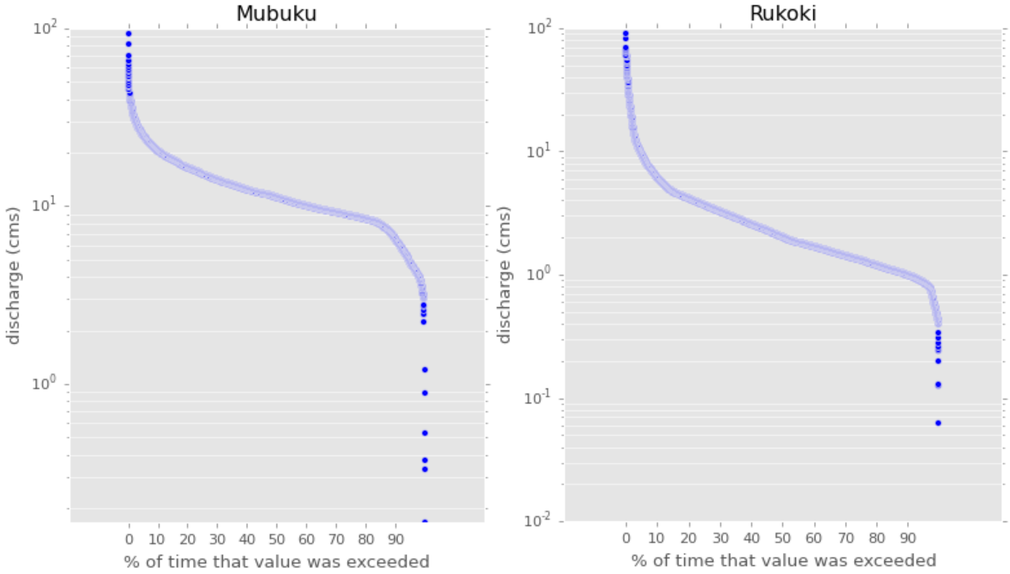

Figure 30. Flow duration curve (% of time that flow is exceeded) for the Mubuku and Nyamwamba (Rukoki location) historic data

3.5 Hotspots for intervention

3.5.1 Satellite-based analysis of forest loss

Forest loss due to conversion to agriculture (often by burning, see example in Figure 31), especially on steep slopes, lead often to degraded lands in this area. A global analysis using temporal analysis of Landsat imagery was carried out by [*Hansen et al.*, 2013] with the objective of characterizing forest extent and change from 2000 onwards. The latest update of this dataset has data on forest loss until 2014. This dataset was used to study forest loss on a high spatial resolution in the study area.

Figure 31. Example of forest on steep slope in Nyamwamba watershed that has partly been burned

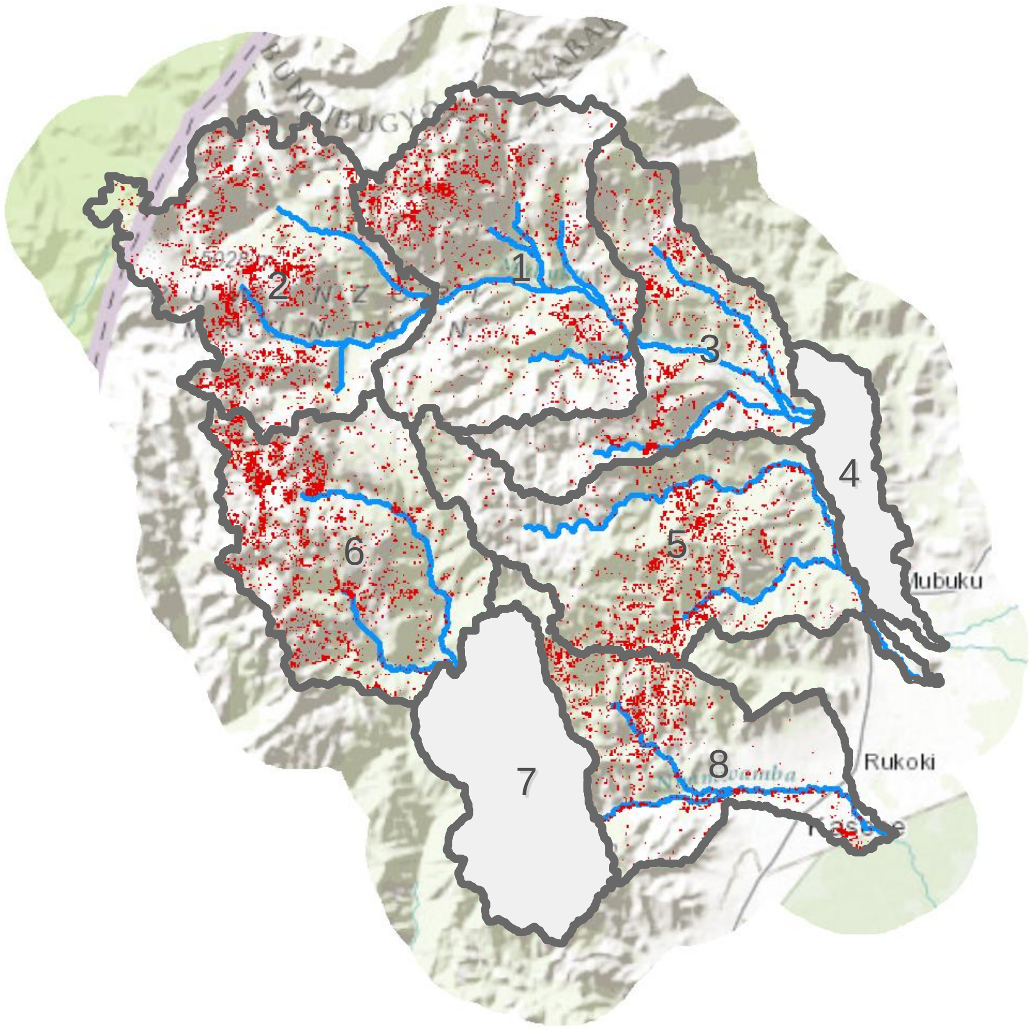

Figure 32. Forest loss analyzed from Landsat imagery in the area [*Hansen et al.*, 2013]

Figure 32 shows forest loss in red over the 2000-2014 period within the study area. As can be seen, quite some forest loss has been detected also in the high mountainous areas within the park (around 650 ha in total), possibly mainly due to a combination of natural succession and forest fires. But the majority of loss has been found in the agricultural areas below the park boundary. Here, forest loss occurred especially in the higher parts of the agricultural areas.

The left panel of Figure 33 shows forest loss in the part of the watershed lower than 2500 meters above sea level (masl), which resembles to the agricultural area. As can be seen, most of the conversion takes place around 2000 masl, close to the park boundary. More than 4% of land has been converted from forest to agriculture over the 15-year period, according to this analysis.

The right panel of Figure 33 shows on which type of slopes these conversions generally occur. The Rwenzori mountains have relatively steep slopes due to its extreme orography. As can be seen, most forest loss is found on very steep slopes of more than 50%.

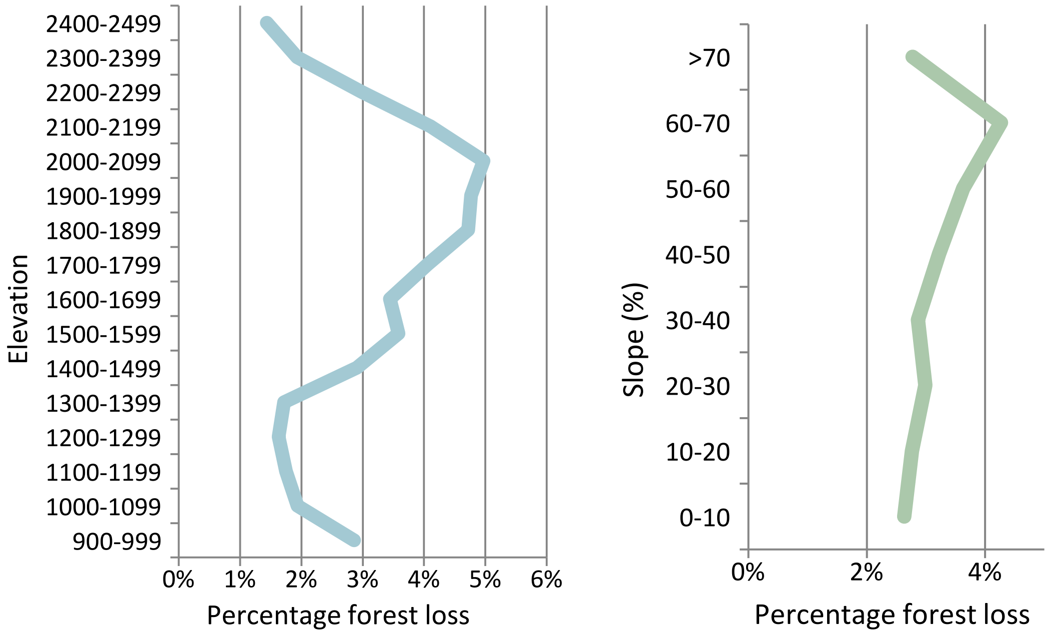

Figure 33. Relative forest loss against elevation and slope

Table 7 shows for the eight sub-basins, (see Figure 32) key biophysical indicators that determine erosion sensitivity. Slope and precipitation are key drivers of erosion and sediment mobilization. Those sub-basins where agriculture and forest loss have a high share, are more prone to erosion.

Table 7. Biophysical watershed indicators including forest loss

Watershed	Mubuku				Sebwe	Nyamwamba		
Indicator / watershed ID	1	2	3	4	5	6	7	8
Average elevation (masl)	2768	3710	2070	1262	1950	3164	1782	1399
Average slope (m/m)	0.48	0.54	0.39	0.17	0.38	0.48	0.44	0.30
Slopes > 0.5 m/m (ha)	3729	3162	1893	111	2312	3085	2109	1286
Mean annual precipitation (mm)	2242	2889	1762	1207	1680	2513	1564	1301
Agricultural area (%)	39	0	76	100	79	18	98	95
Forest loss from conversion (ha)	86	0	157	33	257	26	194	207
Relative forest loss (%)	3	0	3	1	4	2	4	3

For the three watersheds, forest loss in the agricultural area is around 70 hectares per year (= 170 acres per year). In this dataset, the last three years show higher loss values then the first three years (Figure 34). It is still under investigation whether this increase is real or attributed to changes in the change detection algorithm and satellite imagery (Landsat 8 instead of 5/7).

In summary, outcomes confirm that forest loss is an ongoing process in the area, and the fact that his occurs mainly on steep slopes suggest there is an urgent need for sustainable land management practices for these converted lands.

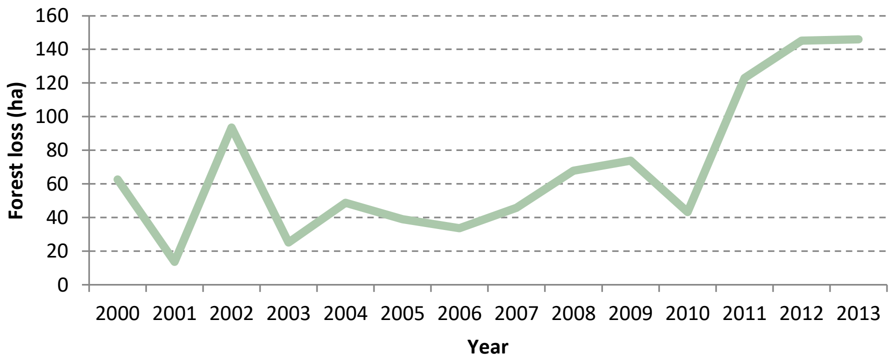

Figure 34. Annual forest loss below 2500 meters altitude (source: Landsat imagery)

3.5.2 Indicators of erosion

From the satellite-based forest loss analysis it has been confirmed that critical areas are the higher elevations in the agricultural area, and steep slopes. To understand how these areas affect erosion, the topographic factor of the USLE erosion equation was derived based on the satellite-based digital elevation model (Figure 35). This supports the identification of areas that are most critical for implementing sustainable land management. The spatially distributed calculation was based on [*Böhner and Selige*, 2006] and [*Moore et al.*, 1991].

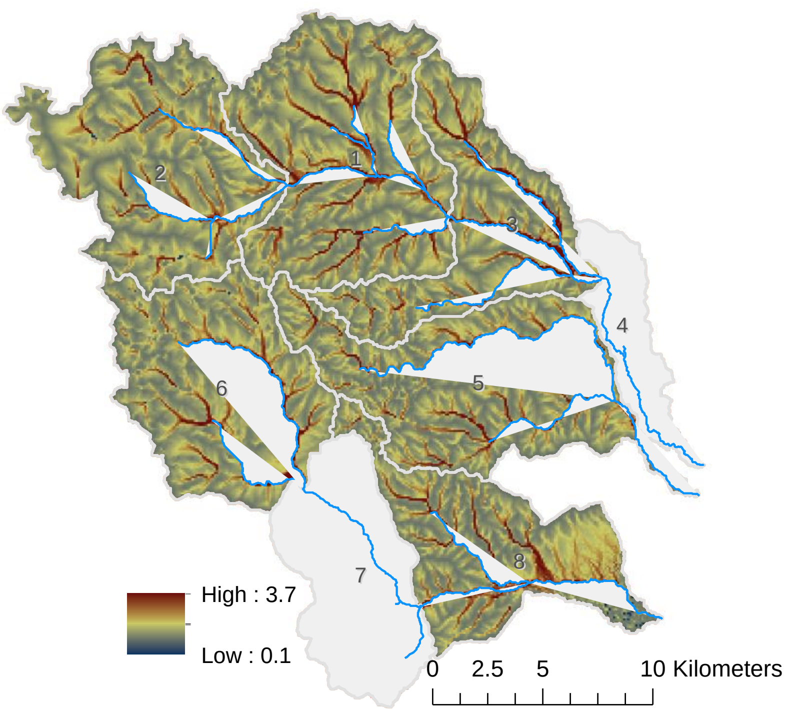

Figure 35. Topographic factor (LS) of the USLE soil erosion equation. High values indicate high risks of erosion.

Another factor to take into account for targeting investments is channel erosivity. A good indicator of channel erosion is the Stream Power Index. This index describes a channel's ability to move sediment, thus its potential to incise, widen, or aggrade. This has implications for flood hazard assessments and riverine erosion.

Protection of riverine areas, and sustainable land management in these areas is recommended especially in those areas where the stream is likely to move high doses of sediments, especially under flooding conditions. The Stream Power Index is based on slope and drainage area [*Moore et al.*, 1991]. It was calculated for the entire area and is represented in Figure 36.

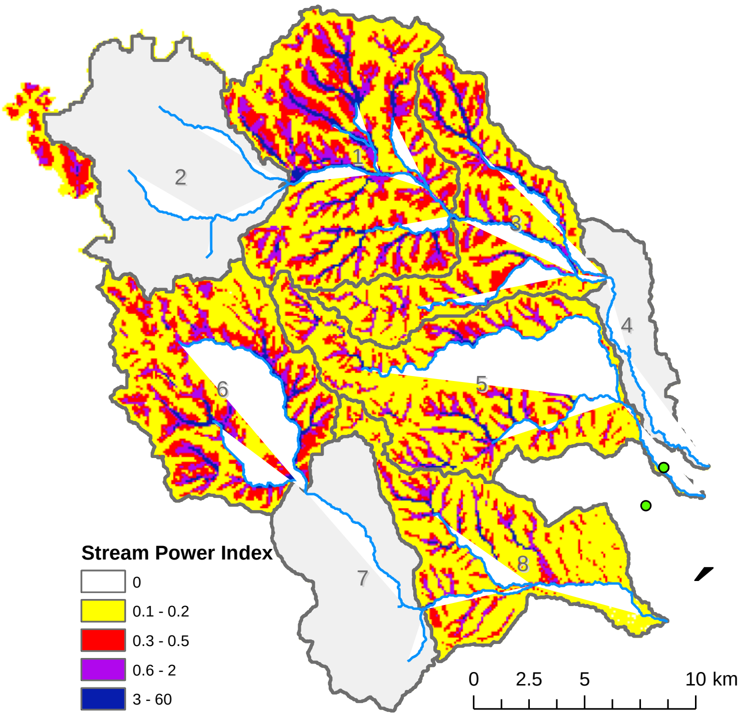

Figure 36. Stream power index for the study area as an indicator of channel erosivity. High values indicate high risk of erosion.

3.5.3 Hotspots

The previous analysis on forest loss and erodibility, together with the agronomic survey were used to generate a hotspot map for intervention. The following considerations were taken into account:

- The agronomic survey confirmed that there is a direct relation between degradation level and slopes: steepest slopes are the first that need to be targeted. Overlay of the surveyed areas confirmed a good match with the USLE erosion LS slope factor. For the hotspots, those areas were selected where LS is higher than 1.0
- The area of intervention should be limited to the areas that can have an impact on the service level of the potential buyer. Therefore, the drainage area of the intake point should be used to limit the hotspots for intervention. As a first step, the area was limited to those that have an elevation between 1500 and 2500 meters above sea level. This corresponds to agricultural areas where most forest loss has been detected (see before), and upstream of water intake for hydropower in Mubuku. Depending on the final buyers in the PES scheme, this can be further limited to the specific drainage area of the point of interest.
- The agronomic survey confirmed that riverine erosion is critical to be targeted. Areas where the SPI index is higher than 0.5 were selected, corresponding to areas where riverine erosion is likely to be significant

The above three criteria, results in a hotspot map for intervention, as shown in Figure 37. Depending on the final business case(s) for the PES scheme, this hotspot map can be further fine-tuned and adapted to the point and area of interest for the specific stakeholder. The "Framework and Guidelines for Water Source Protection" of the Directorate of Water Resources Management (2012) can be used for the delimitation of a specific point of interest.

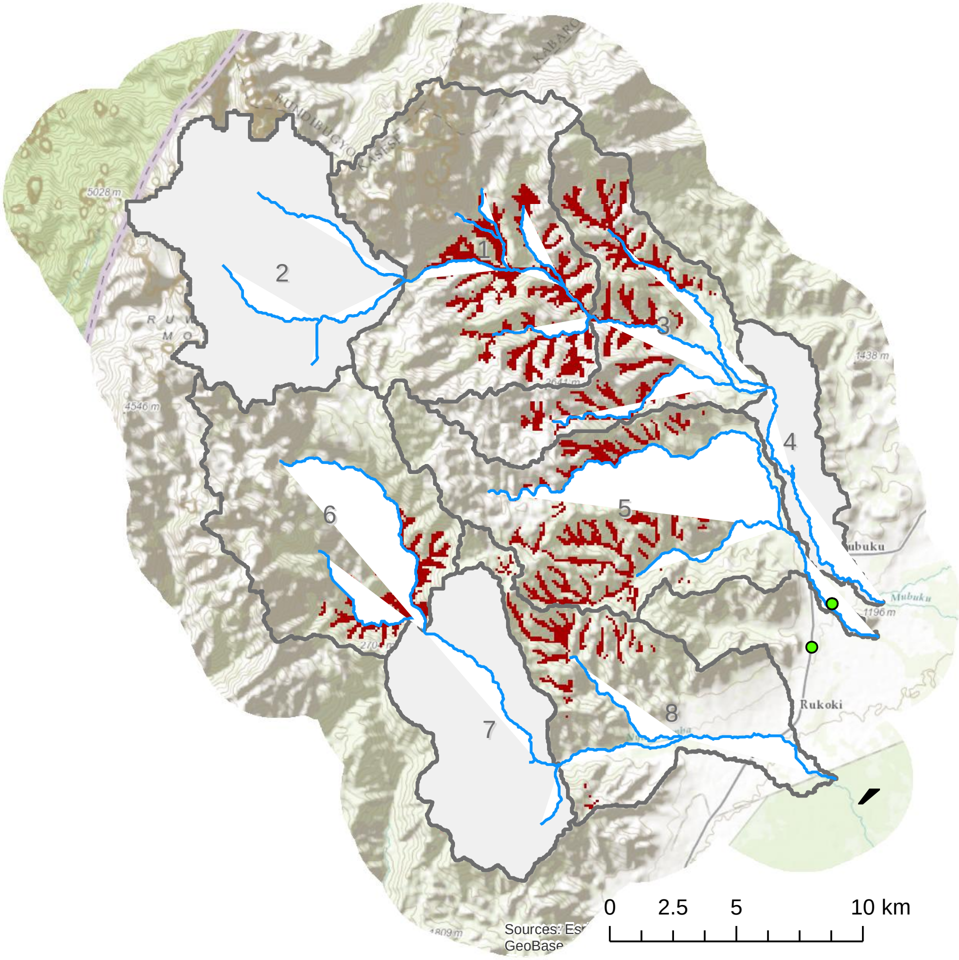

Figure 37. Priority areas for intervention of sustainable land and water management practices.

3.6 Potential downstream benefits

To build a case for potential buyers of the PES scheme in the study area, the potential impact of the investments is analyzed using the WEAP simulation model. The following can be considered a sensitivity analysis that should give insight in how the scale of implementation and potential measures may affect downstream variables that are of interest to these stakeholders. The modeling assessment was based on best data available, but for more detailed and precise assessments, more data will be needed. In summary, the results presented here should be considered as a scoping analysis that shows the relative benefits for downstream water users.

The analysis focuses on 3 aspects that may potentially generate revenues to downstream stakeholders and thus motivate them to be involved and contribute to the PES scheme. These aspects are:

- Hydropower production potential
- Reservoir sedimentation (Mubuku irrigation scheme)
- Sediment loads (municipal water supply)

3.6.1 Overall impacts on flows and sediments

Three groups of measures were analyzed: terracing interventions, agroforestry practices and mulching practices (see details in the Methodology section). These were studied under different implementation levels, giving priority to the steepest slopes in each sub-basin. For example, a 5% implementation of terracing in the watershed means that terraces are implemented on 5% of the steepest slopes in the agricultural area of the watershed.

Economic activities downstream are affected by:

- Low flows, that may cause that certain operations (hydropower for example) are functioning below full capacity, and thus causing a net loss
- High peak flows causing high turbidity (i.e. sediment concentrations) –affecting downstream operations due to damage on for example turbine equipment or incurring costs to water supply
- Sediment loads (i.e. sediment yields expressed in tonnes/day) – causing reservoir sedimentation and thus loss of capacity, increasing maintenance costs.

Figure 38 and Figure 39 show how the measures influence peak flows (95% percentile of daily flows) and low flows (5% percentile of daily flows), for both watersheds. As can be seen terracing has the highest relative impact, and mulching lowest. In the Mubuku watershed, peak flows can be reduced by 10% when the measure is implemented in 25% of the agricultural area. For the Nyamwamba, reductions for this implementation level are around 35%. Nyamwamba watershed has a much higher share of agricultural area (see Table 5) then Mubuku watershed, so relative impacts are much higher.

Low flows (Figure 39) have the potential to increase around 20% in Mubuku and 40% in Nyamwamba watershed, when the measure is implemented in 25% of the agricultural area. But even a 10% adoption of the measure can result in significant impacts on low flows.

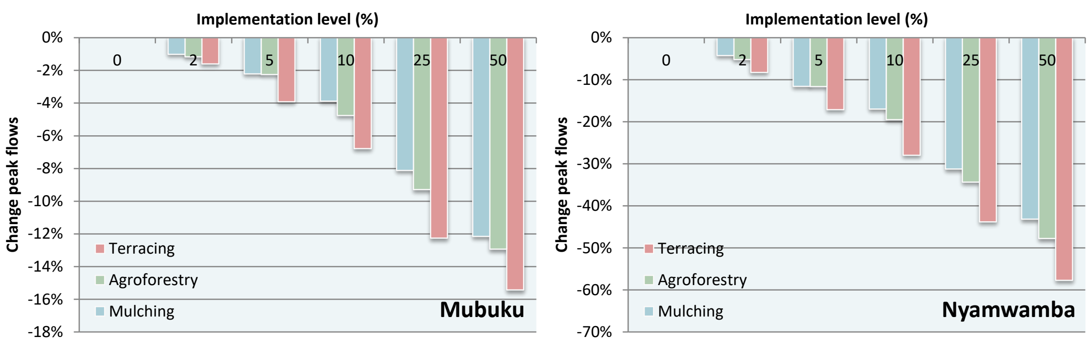

Figure 38. Impact of intervention measures on peak flows (95% percentile of daily flows)

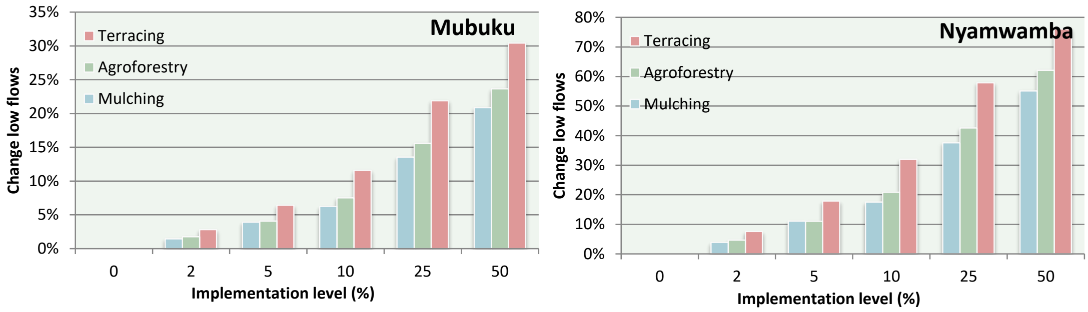

Figure 39. Impact of intervention measures on low flows (5% percentile of daily flows)

Using the sediment rating equation, sediment concentrations are calculated (details in Methodology section). Sediment concentrations are directly related to turbidity that can be easily measured in field campaigns. By multiplying sediment concentrations (mg/l) with flows (m3/s), sediment loads (tonnes/day) can be derived, expressing how much sediment yields a certain point of interest.

Figure 40 shows the impact on sediment load, based on the daily simulations of flow and the sediment rating curve. Also here impacts are much higher in Nyamwamba due to the relative high share of agricultural area in the watershed. Sedimentation can be reduced by 10% in Mubuku and 30% in Nywamwamba when measures are implemented in 10% of the agricultural area (steepest slopes).

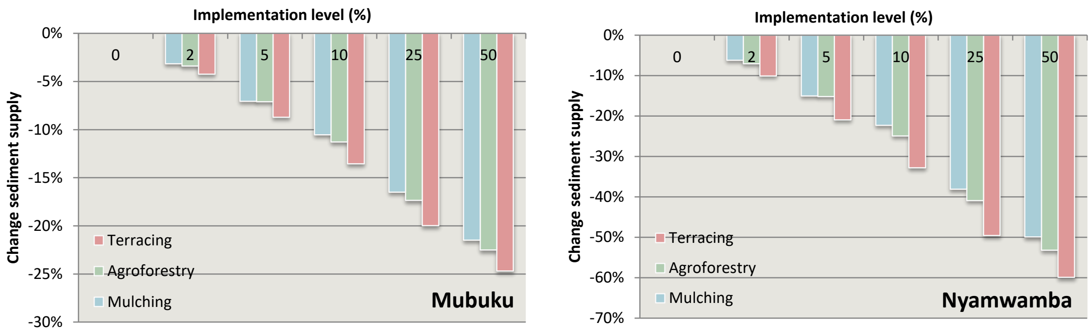

Figure 40. Relative impact of measures on average sediment load

In the following sections, the impact on the services of five potential buyers in the PES scheme is further detailed. They include three hydroelectric power plants depend on water flows from River Mubuku: Kilembe mines power plant (Mubuku I), Kasese Cobalt Company power plant (Mubuku III), and the Mubuku II power station. Mubuku III is not currently operational. Besides, also the case is detailed for the Mubuku irrigation scheme, and the water supply for Kasese.

The above figures and outcomes also support a potential case for Hima Cement: too low flows, and high peak flows may affect their operations. Stakeholder consultation should reveal how they can exactly benefit from the changes in flow regime as shown previously.

3.6.2 Case for the Mubuku I Powerplant

Benefits from upstream investments in the watershed for hydropower production in the Mubuku I powerplant, owned by Kilembe Mines, can be achieved mainly by:

1. A reduction in sediment concentrations in the turbined flows for hydropower, thus reducing wear and tear on turbine equipment and reducing maintenance costs.
2. An increase in dry seasons' flows and thus an increase in power production during the dry season.

Figure 41 shows the impact on sediment concentrations for the 25% implementation level of the terracing scenario. The figure demonstrates that especially the sediment concentration levels that are exceeded in around 30% of time will be reduced significantly (note the logarithmic scale). Damage occurs mainly during peak flow events, when high concentrations are reached and coarser sediment enters in suspension.

Figure 41 suggests that it is very likely that the abrasive damage on turbine equipment will be reduced, leading to a potential saving in maintenance and replacement costs. Also temporal shut-downs of plant due to extreme flows with very high sediment loads can be reduced. More detailed information and analysis of operations together with an economic analysis can provide insight in the potential economic benefits.

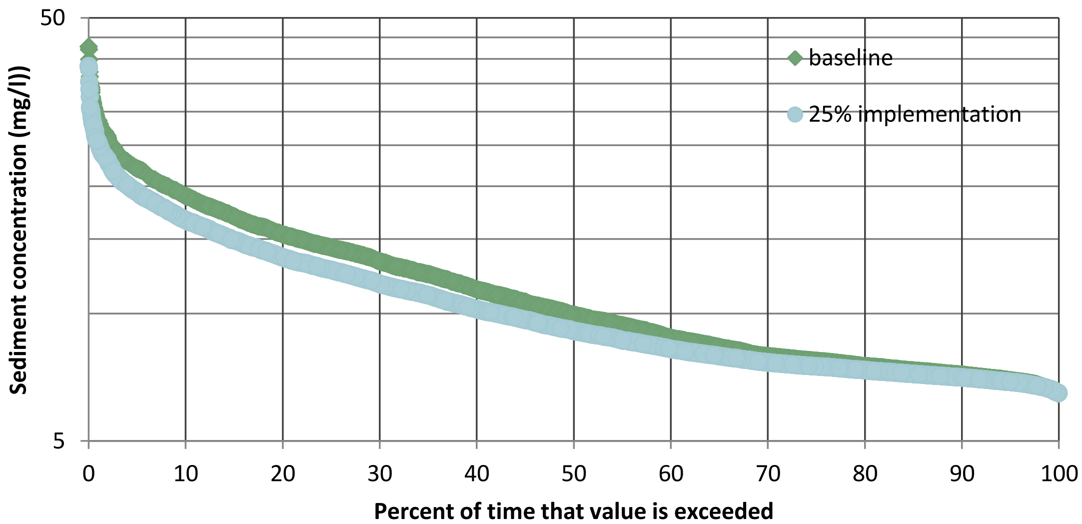

Figure 41. Sediment concentration duration curves for baseline and implementation of terraces in 25% of the area at Mubuku I powerplant

Another potential gain from catchment interventions upstream is the increase of low flows in the dry season. Low flows can be increased as shown in section 3.6.1. During the dry season, power production is commonly below full capacity. Therefore, increases in flows during the dry season can lead to increased power production.

The potential increase in power production has been analyzed for the Mubuku I power plant. Figure 42 shows for different implementation levels the impact of terracing on power production. Table 8 includes the same information but also for the other interventions.

Please note that this calculation is done with the actual capacity. Powerplant owner has indicated that it is planning to increase its capacity to 12 MW, instead of 5 MW currently. With the increased capacity, it is likely that the plant is operating a larger part of the year below full capacity (dry seasons). Thus, the potential gain may be even higher in that case.

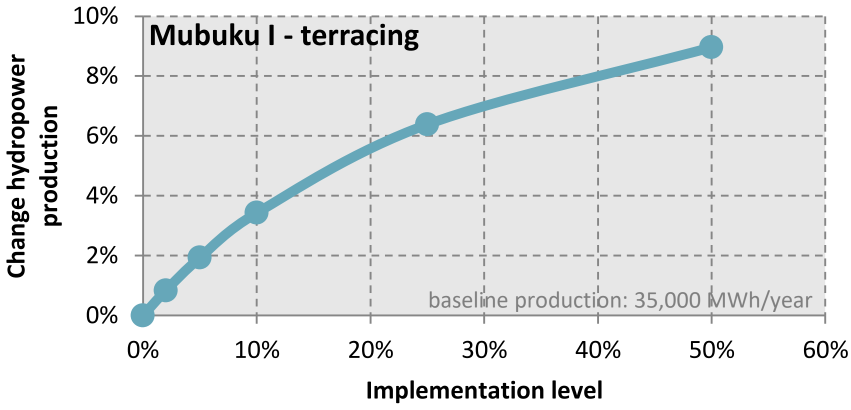

Figure 42. Change in hydropower production by implementing terracing

Table 8. Impacts on hydropower production of different measures for Mubuku I facility

	Implementation level (%)					
Scenario	**50**	**25**	**10**	**5**	**2**	**0**
Terracing	9%	6%	3%	2%	1%	0%
Agroforestry	7%	5%	2%	1%	1%	0%
Mulching	7%	4%	2%	1%	0%	0%

As shown, the owner of Kilembe mines can be considered a potential buyer in the PES scheme because the hydropower facility in the Mubuku watershed can benefit from increased flows during the dry season and lower harmful sediment concentrations. In the Nyamwamba watershed where the mines are located, it is not at all clear whether the mining operations can benefit from upstream interventions: sediment loads and low flows are likely not an issue of concern in the current situation.

3.6.3 Case for the Mubuku II Powerplant

Benefits from upstream investments in the watershed for hydropower production in the Mubuku II powerplant, owned by Tronder Power, can be achieved mainly by:

3. A reduction in sediment concentrations in the turbined flows for hydropower, thus reducing wear and tear on turbine equipment and reducing maintenance costs.
4. An increase in dry seasons' flows and thus an increase in power production during the dry season.

Figure 41 shows the impact on sediment concentrations for the 25% implementation level of the terracing scenario. The figure demonstrates that especially the sediment concentration levels that are exceeded in around 30% of time will be reduced significantly (note the logarithmic scale). Damage occurs mainly during peak flow events, when high concentrations are reached and coarser sediment enters in suspension.

Figure 41 suggests that it is very likely that the abrasive damage on turbine equipment will be reduced, leading to a potential saving in maintenance and replacement costs. More detailed information and analysis of operations together with an economic analysis can provide insight in the potential economic benefits.

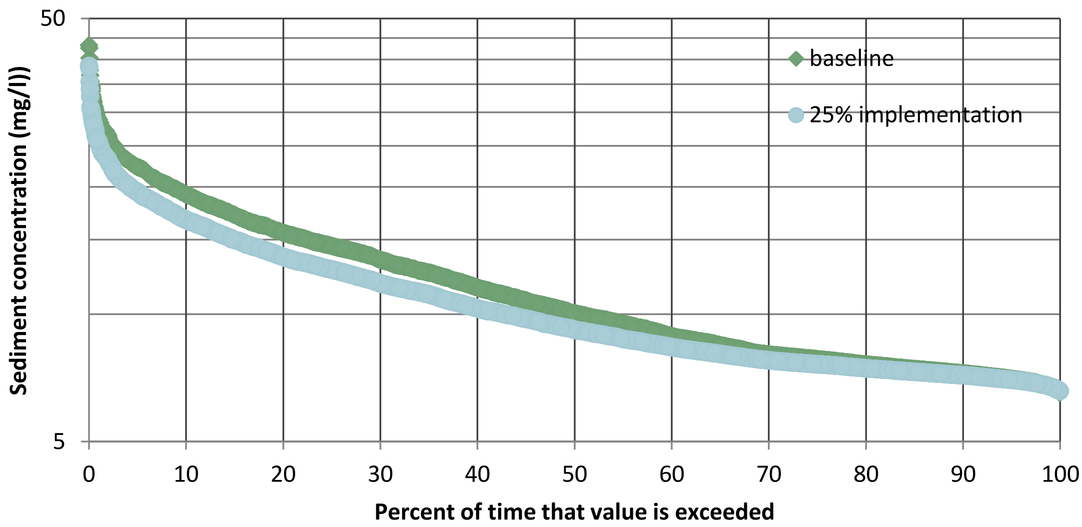

Figure 43. Sediment concentration duration curves for baseline and implementation of terraces in 25% of the area at Mubuku II powerplant

Another potential gain from catchment interventions upstream is the increase of low flows in the dry season. Low flows can be increased as shown in section 3.6.1. During the dry season, power production is commonly below full capacity. Therefore, increases in flows during the dry season can lead to increased power production.

The potential increase in power production has been analyzed for the Mubuku I power plant. Figure 42 shows for different implementation levels the impact of terracing on power production. Table 8 includes the same information but also for the other interventions.

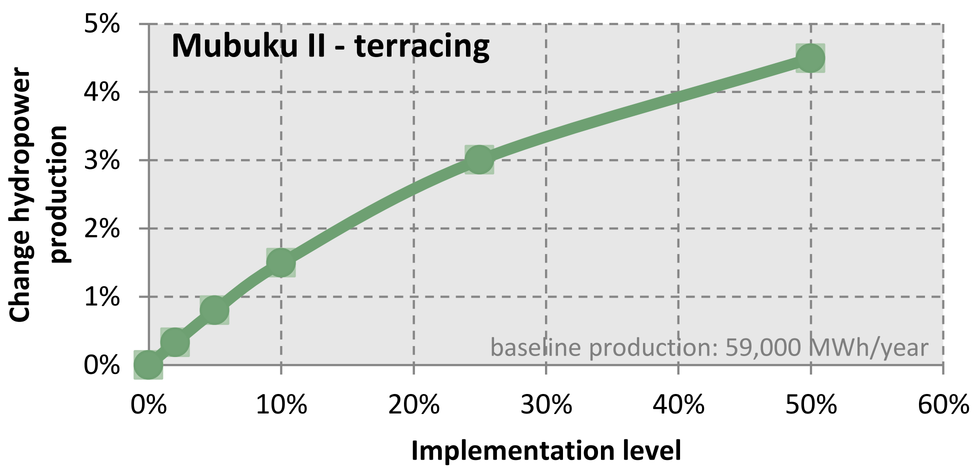

Figure 44. Change in hydropower production by implementing terracing

Table 9. Impacts on hydropower production of different measures for Mubuku II facility

	Implementation level (%)					
Scenario	**50**	**25**	**10**	**5**	**2**	**0**
Terracing	4.5%	3.0%	1.5%	0.8%	0.3%	0.0%
Agroforestry	3.4%	2.1%	1.0%	0.5%	0.2%	0.0%
Mulching	3.2%	2.0%	0.9%	0.6%	0.2%	0.0%

3.6.4 Case for the Mubuku III Powerplant

Benefits from upstream investments in the watershed for hydropower production in the Mubuku II powerplant, owned by KCCL, can be achieved mainly by:

5. A reduction in sediment concentrations in the turbined flows for hydropower, thus reducing wear and tear on turbine equipment and reducing maintenance costs.
6. An increase in dry seasons' flows and thus an increase in power production during the dry season.

Figure 41 shows the impact on sediment concentrations for the 25% implementation level of the terracing scenario. The figure demonstrates that especially the sediment concentration levels that are exceeded in around 30% of time will be reduced significantly (note the logarithmic scale). Damage occurs mainly during peak flow events, when high concentrations are reached and coarser sediment enters in suspension.

Figure 41 suggests that it is very likely that the abrasive damage on turbine equipment will be reduced, leading to a potential saving in maintenance and replacement costs. More detailed information and analysis of operations together with an economic analysis can provide insight in the potential economic benefits.

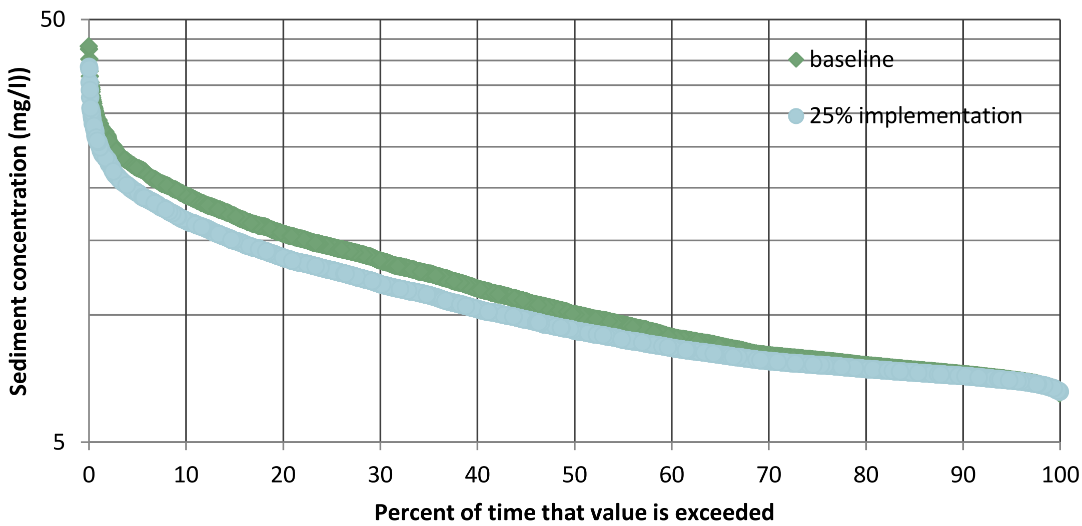

Figure 45. Sediment concentration duration curves for baseline and implementation of terraces in 25% of the area at Mubuku III powerplant

Another potential gain from catchment interventions upstream is the increase of low flows in the dry season. Low flows can be increased as shown in section 3.6.1. During the dry season, power production is commonly below full capacity. Therefore, increases in flows during the dry season can lead to increased power production.

The potential increase in power production has been analyzed for the Mubuku III power plant. Figure 42 shows for different implementation levels the impact of terracing on power production. Table 8 includes the same information but also for the other interventions. Please note that the drainage area for this plant is practically the same as for Mubuku II, so the relative differences are the same as for Mubuku II.

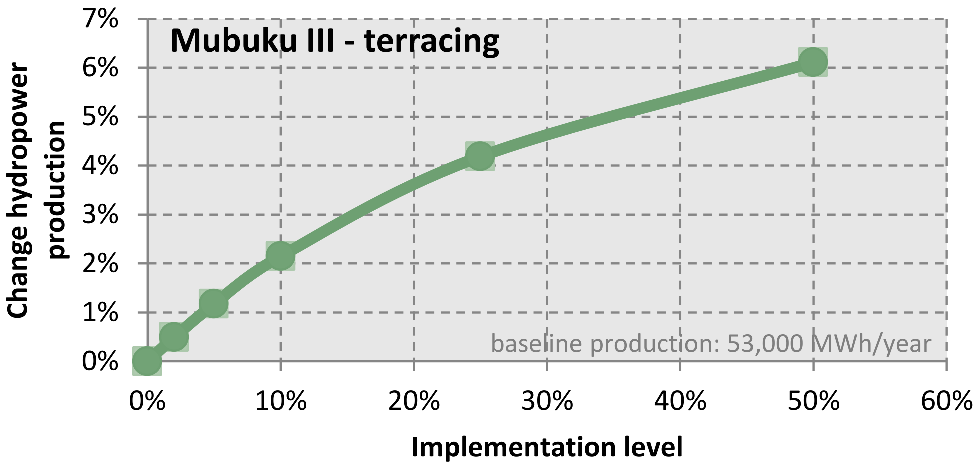

Figure 46. Change in hydropower production by implementing terracing

Table 10. Impacts on hydropower production of different measures for Mubuku III facility

	Implementation level (%)					
Scenario	**50**	**25**	**10**	**5**	**2**	**0**
Terracing	4.5%	3.0%	1.5%	0.8%	0.3%	0.0%
Agroforestry	3.4%	2.1%	1.0%	0.5%	0.2%	0.0%
Mulching	3.2%	2.0%	0.9%	0.6%	0.2%	0.0%

3.6.5 Case for the Mubuku Irrigation Scheme

Principal benefits that can be expected for the Sebwe irrigation scheme are related to reduced costs from problems with sedimentation. The dam from which water is diverted requires to be desilted regularly. Reducing sediment loads in the Sebwe river can make sure that this will be necessary less often. The same applies for the irrigation reservoir that buffers some of the water for the irrigation scheme.

Figure 47 shows the sediment concentration duration curve for the Sebwe irrigation scheme intake, for the baseline and the 25% implementation level. There is a clear impact on sediment concentration especially for the higher concentrations. Also Figure 48 confirms that with this implementation level sediment loads can be reduced by around half. The nonlinear trend in this figure shows clearly the relative impact that the steepest slopes have on erosion and sediment yield.

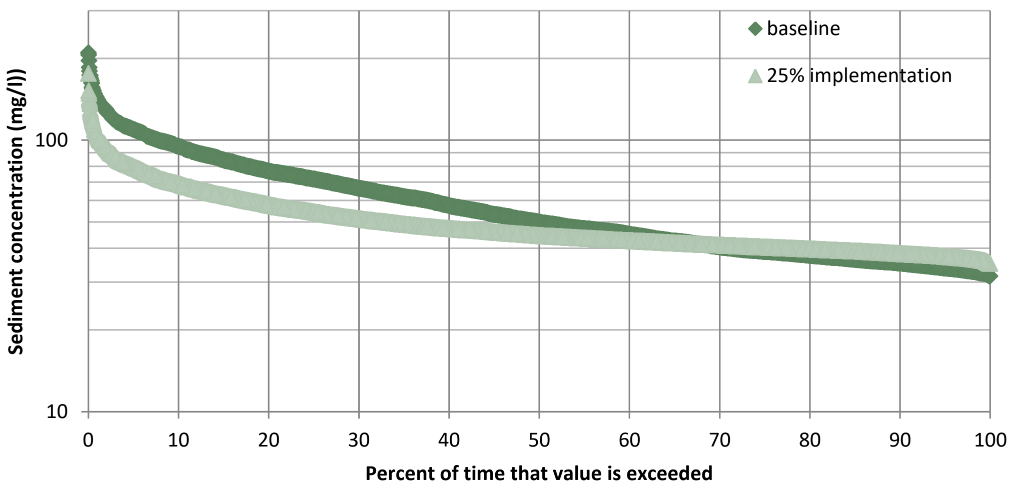

Figure 47. Sediment concentration curve for the Sebwe irrigation intake, for baseline and 25% implementation level of terracing.

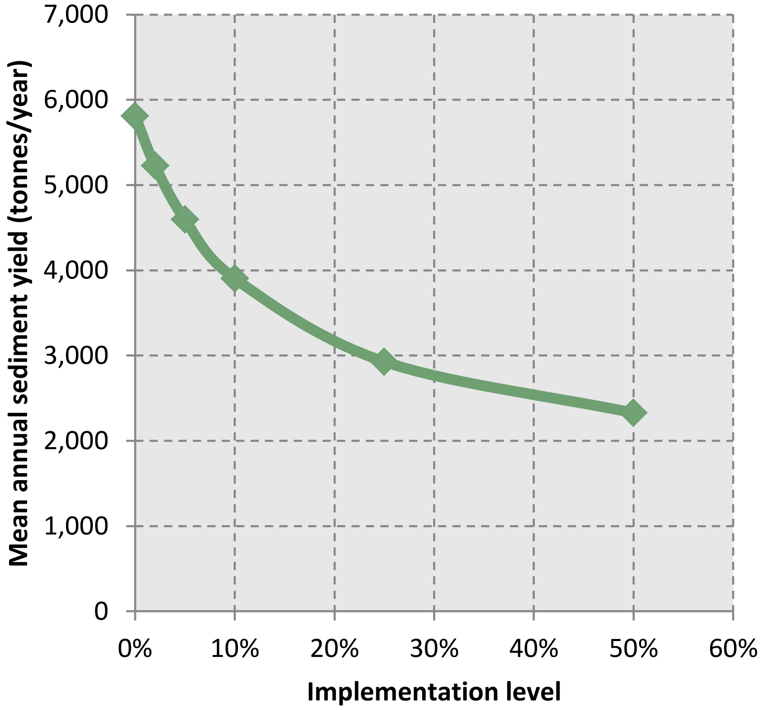

Figure 48. Reduction in sediment loads of Sebwe river under different implementation levels of the terracing scenario.

Besides these reduction in sediment loads also a potential benefit from more regulated flows can be expected for the irrigation scheme (les peak flows, higher low flows.

Table 11. Impacts on sediment load of different measures for Sebwe river

	Implementation level (%)					
Scenario	**50**	**25**	**10**	**5**	**2**	**0**
Terracing	-39%	-32%	-22%	-14%	-7%	0%
Agroforestry	-35%	-27%	-17%	-11%	-5%	0%
Mulching	-33%	-26%	-16%	-10%	-4%	0%

3.6.6 Case for Domestic Water Supply

Water availability exceeds water demand in both watersheds, as detailed in the Mubuku/ Nyamwamba Sub-catchment Management Plan (2012). Still, low flows are an issue to National Water & Sewerage Corporation (NWSC). Results shown in the section 3.6.1 indicate that flows during the dry season are likely to increase. This can be relevant for Kasese town but also to other communities. Also reduced peak flows (section 3.6.1) can reduce number of days with shut-downs.

Water quality (sediments and contaminants) are likely a more important issue of concern to NWSC. Due to the ongoing upstream contamination of the mining industry, a significant part of the water for Kasese town is abstracted from groundwater. Some communities however are also provided with water directly abstracted from the river. These communities may potentially benefit from a reduction in sediment yield due to upstream investments.

Figure 49 shows the sediment concentration duration curve for the stream just upstream of Kasese town, where these communities are located. The model analysis shows that sediment concentrations can be reduced drastically. Table 12 shows the relative reductions in sediment load for a point near to Kasese. Conversations with NWSC should reveal how sediment loads affect their business operations in the current situation.

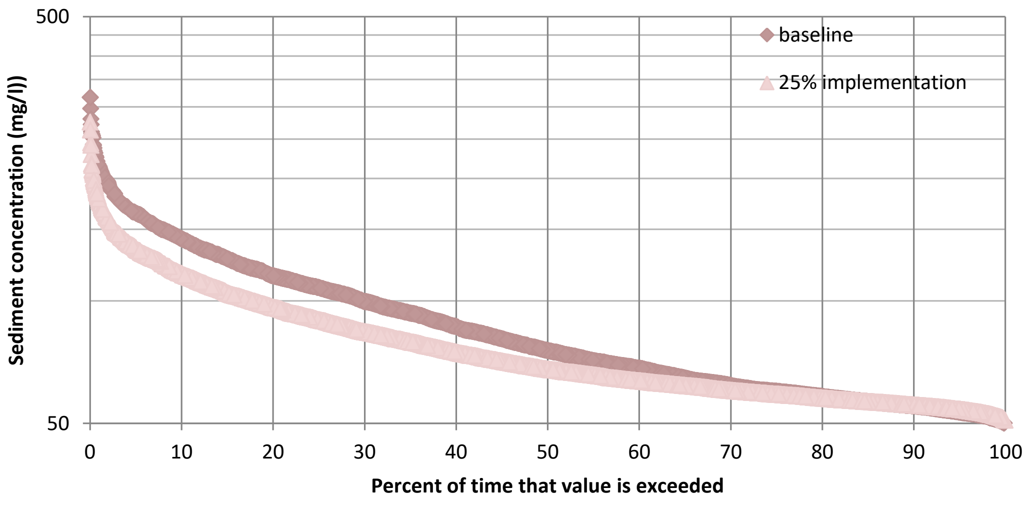

Figure 49. Sediment concentration duration curve for reach upstream of Kasese town for the intervention measures of terraces on 25% of the area.

Table 12. Impacts on sediment loads (percentage reduction) of the different measures in Nyamwamba river – reach at Kasese town

	Implementation level (%)					
Scenario	**50**	**25**	**10**	**5**	**2**	**0**
Terracing	-39%	-32%	-22%	-14%	-7%	0%
Agroforestry	-35%	-27%	-17%	-11%	-5%	0%
Mulching	-33%	-26%	-16%	-10%	-4%	0%

4 Conclusions

A preliminary assessment was carried out on the hydrological and agronomic factors that determine the potential of a PES scheme in the Mubuku and Nyamwamba watersheds draining from the Rwenzori National Park. A combination of field-data collection, surveys, data analysis and simulations has provided a better understanding of the opportunities and limitations of setting up the scheme. The following conclusions can be drawn:

- The protected area in the park is critical for a reliable water supply to downstream water users, both in terms of quantity as in quality. This is especially the case for the Mubuku watershed. However, the catchment response (water quantity and quality) is very dependent on the agricultural area. Simulations have confirmed that interventions in the agricultural area can significantly influence flows and sediment yield.
- Land management practices can make a positive impact on downstream water quantity and quality. Peak flows can be reduced significantly, while baseflow (low flows) can increase. Reduced fast runoff will lead to reduced erosion rates and thus less sediment yield.
- The satellite-based mapping of priority areas confirms that forest loss is an ongoing process in the watersheds. Spatial patterns, trends, and the relation of this development with elevation and slope have been analyzed. Based the agronomic survey, the forest loss analysis, and two erosivity indices, an identification of hotspots for interventions was made.
- Downstream water users (hydropower, irrigation and water supply) can expect noticeable impacts on their water supply and the quality of water. Impacts were estimated based on best data currently available, and confirm that interventions can cause additional revenues and/or reduced costs to these utilities. For economic benefits, a subsequent analysis should be carried out, based on more detailed local datasets and modeling.
- The field-based agronomic assessment confirms that degradation of the landscape is related to unsustainable management practices in the agricultural area. Indeed, the focus group discussions with the water user associations (farmers) indicated that erosion and mineral deficiency is a key problem they face. Only very few farmers currently perform soil and water conservation practices such as trenches, and vegetated terraces were seen in some areas.

Impacts of interventions on streamflow are significant when targeting around 5% of the catchment area. These impacts concern peak flow reduction and increase of low flows in dry season. Especially in Nyamwamba watershed the impacts are noticeable, even when targeting 2% of the area. The Mubuku catchment has a more attenuated response due to the larger upstream area, but still significant benefits can be obtained. For hydropower, when targeting around 25% of watershed, increases in hydropower of around 5% are predicted.

In terms of sediments, significant impacts can be obtained when targeting at least 5% of the catchment area. When targeting 10% of the area, around 10% reduction can be obtained in the Mubuku watershed, and 20% in the Nyamwamba watershed. The reductions are likely to occur mainly during the high flow season. This can be relevant for the relying services (hydropower, water supply, irrigation) that are affected by high sediment loads, increasing maintenance costs and forcing temporary shut-downs.

This scoping study has delivered as tangible result also a database that was built including the most relevant datasets for the PES scheme (see Annex III). GIS data has been gathered from the public domain and will be available for further analysis, as well as the WEAP simulation model. A monitoring plan (see Annex I) has been developed based on the field work experiences and stakeholder inputs.

Overall, the study shows that there is scope for the implementation of a PES scheme, from a hydrologic and agronomic perspective. Investing in upstream areas, to promote the adoption of sustainable land management technologies can lead to benefits downstream in terms of water quantity and quality.

Recommendations

Based on the outcomes of this study, the next critical step is to convince downstream stakeholders of a possible business case and make sure they engage fully with the project. When they are onboard, a detailed analysis should follow that includes cost-benefit analysis of the different interventions and management scenarios.

A follow-up business case analysis should also quantify potential benefits in terms of crop yield and livelihood improvement. Agro-hydrological modeling is recommended for this purpose, building upon the agronomic survey and the socio-economic study. This allows a more detailed analysis of erosion patterns and the spatially explicit calculation of benefits for farmers.

It is critical that the baseline dataset that has been gathered so far will be extended for at least one year, to capture well the temporal variability (rain and dry seasons). Then, it is feasible to carry out more detailed erosion modeling (sources and sinks), and develop a fully distributed hydrological model that can be used for monitoring the PES scheme.

Data collection for monitoring hydrological PES schemes is critical, but should be complemented with hydrological modeling. Changes and trends from field data are difficult to interpret and link with upstream activities. It is thus essential to have a robust and detailed hydrological model as one of the backbones of the PES scheme in order to communicate achievements to sellers and buyers in a convincing and technically sound way.

5 References

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6 Annex I – Monitoring Plan

Given the fact that proposed PWS project will be a multi-stakeholder process, we propose a participatory monitoring plan where the different stakeholders will have different roles and components to monitor during project implementation. The suggested components of the monitoring plan include

- Agronomic practices
- Hydrological and water quality monitoring
- Meteorological monitoring (weather)

1. Monitoring objectives

The overall objective of the monitoring plan is to assess progress of PES implementation but also monitor the effectiveness of interventions on water quality and quantity. The monitoring results will help guide the reward system for the PES scheme.

2. Monitoring sites description

The monitoring sites will be selected from those in which the assessment was done during the baseline studies. The proposed monitoring sites should have a reference site likely inside the park on studied rivers (sites used in the assessment can be maintained). The other monitoring sites should target the hotspots of degradation and intervention, and water abstraction points.

On Nyamwamba, a site below the hotsprings and Road Barrier should be able to assess improvements in water quality as a result of sustainable landuse practices.
The monitoring sites should take into consideration of ease of access for example near location of rangers outposts.

3. Frequency of monitoring

The frequency of monitoring will be less intensive but will target the wet and dry seasons for water quality and quantity while agronomic practices can be monitored once a year.
Water level and flows should be measured on a daily basis at a fixed time. Turbidity and or water transparency as indicators of sediment load can also be measured on a daily basis.

Meteorological data will be monitored following standard practice on a daily basis. UWA has automated weather stations at different altitudes in the Mubuku Catchment. An additional automated weather station should be considered for the Nyamwamba sub catchment.

4. Protocol for agronomic practices

The protocol for agronomic practices will closely follow the tools used during the baseline studies but with modifications where necessary. Some of the proposed the proposed monitoring indicators for agronomic practices are presented in the table below:

Monitoring Indicator	Method /source of data	Responsible institutions
Coverage of recommended practices (length, acreage)	Farm level	WWF, Kasese LG
Erosion (Monitoring)	Farm level	WWF, Makerere University, Kasese LG
Vegetation cover	Satellite imagery	WWF, Consultant, Kasese LG
Change in energy use (quantities)	Household level	WWF, Consultant, Kasese LG
Generation and use of farm manure (quantities, types)	Farm level	WWF, Consultant, Kasese LG
Changes in yield, land productivity (yield per ha)	Farm level	WWF, Consultant, Kasese LG

5. Protocol for water quality / hydrology

The protocols for water quality will closely follow the tools used during the assessment but can be modified dependent on equipment availability and manpower.
Daily monitoring of turbidity and water transparency can be done by rangers at established sites. DWRM and a consultant can train rangers on how to use the equipment.
Detailed water quality assessments can be carried out by DWRM twice a year, at peak of wet season and during a dry season.

6. Protocol for meteorological measurements

The protocols for meteorological measurements will be standard following the national guidelines. UWA is already carrying out monitoring of these. Other weather stations may need to be set up within the Nyamwamba watershed.

7. Monitoring requirements

The monitoring requirements will take into consideration the needs of the different stakeholders during project implementation. These will be concretized when all baseline studies are completed and priorities selected by project partners with help of consultants.

7.1. Personnel and time

The potential personnel to be used in the monitoring such as from the directorate of water, UWA and district authorities already have the skills to implement the monitoring. Further training may be required for some though. The rangers will need further training especially on how to use the water level gauging stations. A maximum of 30 minutes is sufficient to measure turbidity and water levels at each site.

District agronomists have the necessary training to carry out the assessment of agricultural practices. Teams of two people can ably handle the assessments at each site.

The private sector responsible for degrading or polluting water sources can also be engaged to invest in monitoring the impacts of their activities. Or they can be invited to be part of the monitoring exercise on a regular basis.

7.2. Experience/training

Most of the proposed personnel have the basic skills necessary to use the equipment suggested. UWA staff may need further training though especially on handling and care for the equipment and data.

7.3. Equipment required

Most of the equipment used during this study such as water quality meters, flow meters, is recommended for use during the monitoring phase.

1. Water quality and hydrology
    a. Turbidity meter; the model to be bought should be rugged to withstand field conditions (explore www.forestry-suppliers.com)
    b. Transparency tube: these are available from forestry suppliers
    c. Water level gauge: simple models are available on the market but if the budget allows, an automated water level logger can be installed.
    d. Flow meter: these range in cost and complexity, a robust and easy to operate model can be procured depending on the available resources.
2. Agronomic practices
    a. Tape measure (50 or 100m)
    b. GPS unit
    c. Camera

7 Annex II – Simulation model details

Model Inputs and parameters

The WEAP model was set-up using the Rainfall-Runoff soil moisture model, based on the following datasets and using the following parameters:

- Sub-basin delineation from digital elevation model (SRTM – see description in section 2.6.1 “Public domain datasets for model input”), at 90m resolution
- Land cover distribution:
  - Agricultural area following GLOBCOVER (see description in section 2.6.1 “Public domain datasets for model input”) dataset, and cross-check with satellite imagery (Google Earth Engine)
  - Other vegetation zones following [*Taylor et al.*, 2009] from elevation:
    - Montane forest from 2200 – 3000 masl (meters above sea level)
    - Heath moss forest from 3000 – 3800 masl
    - Afroalpine zone above 3800 masl
  - The above leads to sub-basin areas and land cover fractions as shown in main document, Table 5.
- Rainfall was based on the FEWS RFE2 dataset (see description in section 2.6.1 “Public domain datasets for model input”)
  - Timeseries for several cells of the 10-km resolution dataset were extracted (daily rainfall from 2001-2014).
  - Mean annual rainfall for this cell is 898 mm
  - This corresponds satisfactory with mean annual rainfall mentioned in [*Taylor et al.*, 2009]: 890 mm
  - Data received from DWRM contained too many data gaps to reliably estimate rainfall totals.
  - Also data from the Global Surface Summary of the Day (GSOD) weather station of Kasese was downloaded and analyzed. It appear to have also considerable number of gaps (around 50% for 2001-2014), although less than in the station data provided by DWRM. Gap filling was carried out using “*monthly mean substitution*”: for the same period (2001-2014). From this filled time series, mean annual rainfall was 750 mm.
- Rainfall gradients were included in model using precipitation lapse rate. This lapse rate was based on [*Taylor et al.*, 2009] that mentions 2600 mm at 3290 masl. This resuls in a lapse rate of $0.7 mm*m^{-1}$
- Average temperature was extracted from the same GSOD station data for Kasese: 24.5 ºC, and a lapse rate was used to account for elevation-dependent temperature gradients: 0.6 ºC / 100m.
- Root Zone Conductivity and Deep Conductivity = 2 mm/day (established by calibration, see below)
- Initial Soil Moisture = 80% (based on simulated soil moisture variability)
- Preferred Flow Direction was assumed to be proportional to the average slope in each sub-basin. Then for each sub-basin the values were scaled based the assumption that the steepest sub-basin (Mubuku upper alpine area) has a preferred flow direction of 1 ((i.e. 100% of infiltrated water to interflow). This parameter was used for the scenario analysis (see below)
- Runoff Resistance Factor: assumed to be proportional to the typical Leaf Area Index of the land cover (Coffee/agricultural area: 1.5, Montane_forest: 9, Heath_moss_forest: 5,

Afroalpine_zone: 3. The proportional factor (0.67) was obtained by calibration. This parameter is used for scenario analysis.

- For the other soil parameters default values have been maintained.

Table 13. Slope histogram (percentiles) and derived Preferred Flow Direction, used for scenarion analysis

WEAP	mean	perc 50	perc 75	perc 90	perc 95	perc 98	max	Pref Flow Direction
Catch_M_high	50	45	67	92	106	124	278	0.86
Catch_M_top	58	55	74	98	118	144	330	1.00
Catch_N_high	49	43	62	87	109	141	358	0.84
Catch_M_high	47	41	62	84	98	117	306	0.80
Catch_M_middle	40	36	52	70	78	86	117	0.68
Catch_M_top	51	47	66	90	107	132	347	0.88
Catch_N_high	43	38	57	77	92	113	261	0.74
Catch_Sebwe	34	34	45	54	60	67	120	0.59
Catch_M_high	49	48	62	76	86	97	180	0.84
Catch_M_middle	42	40	53	66	75	87	178	0.72
Catch_M_top	38	34	55	70	79	91	177	0.64
Catch_N_high	55	54	68	83	93	107	197	0.94
Catch_N_low	31	30	40	50	56	66	96	0.53
Catch_N_middle	46	47	58	67	72	78	107	0.79
Catch_Sebwe	36	34	46	59	67	77	172	0.61
Catch_M_high	45	46	59	70	78	86	143	0.77
Catch_M_low	17	11	25	42	50	58	94	0.29
Catch_M_middle	38	39	53	65	73	83	159	0.65
Catch_N_high	43	43	59	71	79	89	138	0.73
Catch_N_low	30	29	47	60	68	77	197	0.51
Catch_N_middle	44	44	57	70	78	87	160	0.75
Catch_Sebwe	39	40	52	63	70	77	142	0.66

Hydropower

Hydropower generation is computed from the flow passing through the turbine, based on the reservoir release or run-of-river streamflow, and constrained by the turbine's maximum flow capacity. If there is too much water, extra water is assumed to be released through spillways that do not generate electricity. So:

$$VolumeThroughTurbine = Min(Release_H, MaxTurbineFlow_H)$$

The maximum turbine flow can be calculated by multiplying the installed generating capacity (MW) with the number of seconds in a month and dividing by what WEAP calls the *HydroGenerationFactor*:

$$MaxTurbineFlowGJ = InstalledCapacityMW * NoSecondsMonth / HydroGenerationFactor_H$$

The *HydroGenerationFactor* is calculated 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/m3 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 0.85. The *PlantFactor* was assumed to be 0.8. Environmental flow requirements as followed by the hydropower plants were assumed to be 1 m3/s (minimum flow in river after abstraction).

A minimum flow was assumed to be left in the river, following environmental flow requirements, of 1.0 m3/s.

The table shows the parameters used for the hydropower calculations. It includes also the mean annual power productions simulated as found in literature, compared to the simulated production based on the daily flow simulations (last column). As can be seen, a good agreement was obtained using these first-order parameters. More detailed data on abstractions and on the facilities could lead to a more precise comparison of observed and simulated power production, evaluating seasonality and inter-annual variability.

Name	**Owner**	**Mean annual power production (GWh)***	**Head**	**Plant Factor**	**Plant Efficiency**	**Maximum turbine flow (m3/s)**	**Environmental flow (m3/s)**	**Available Capacity (MW)***	**Simulated power production (GWh/yr)**
Mubuku I	Kilembe	34	200	0.8	0.85	3.7	1.0	5	35
Mubuku II	Tronder	74	160	0.8	0.85	9.4	1.0	10	70
Mubuku III	KCCL	52	150	0.8	0.85	8.0	1.0	8	53

*Source: http://enipedia.tudelft.nl/wiki/Uganda/Powerplants

Calibration

No recent data on streamflow was available for this study. Only historic data in the period 1960-1980 was available, when most likely the watershed conditions were different (less intensively developed). So only a first-order calibration was possible, accepting a level of difference with historic observations given the changes since then.

Calibration was done using the following parameters:

- Root zone conductivity (Deep Conductivity assumed to be equal)
- Runoff Resistance Factor (assumed to be proportional to Leaf Area Index)

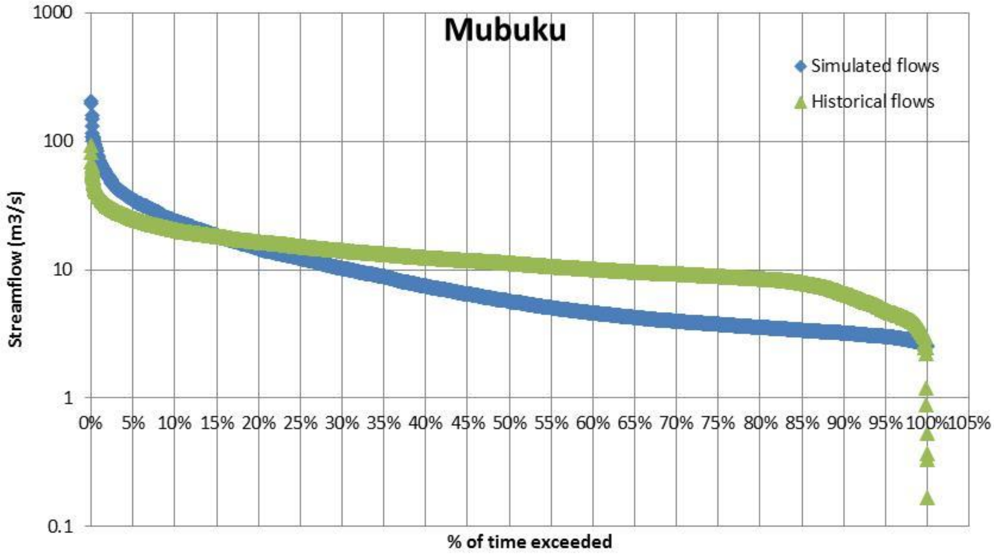
A relative error PBIAS was calculated for the three watersheds, calculated as

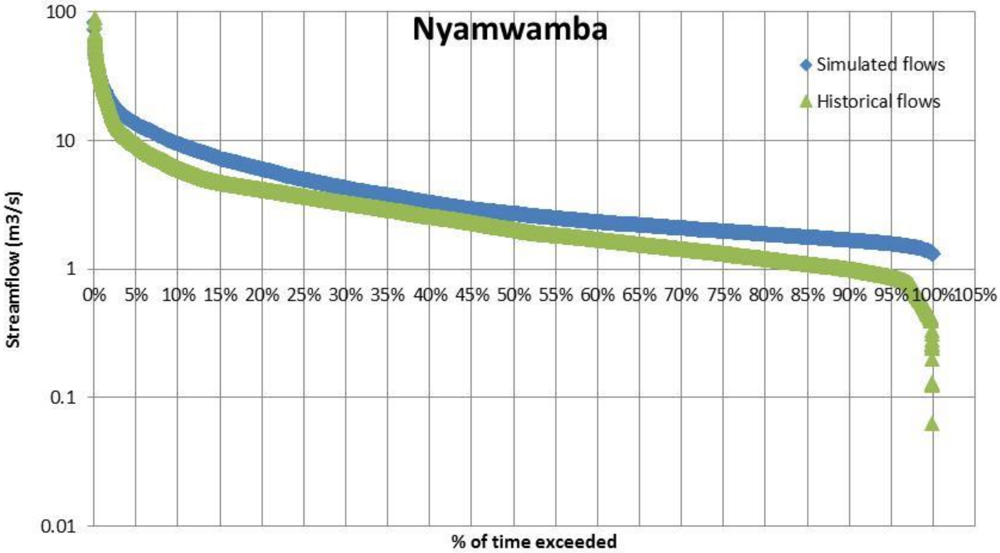
$$PBIAS = \frac{Q_{avg}^{sim} - Q_{avg}^{obs}}{Q_{peak}^{obs} - Q_{low}^{obs}}$$

This relative error PBIAS was

- -10% for Mubuku: so simulation model for current situation and based on best available data simulates lower average flows then historical flows. Further investigation and streamflow data sampling could reveal what the reason behind this difference could be (data, land cover change, climate change, ..)
- + 14% in Nyamwamba: model simulates higher flows than historical flows, potentially due to deforestation which tend to increase average flows, but also increases peak flows (see also flow duration curve below)
- + 4% in Sebwe: model simulations and historical data have similar average flows

The diagrams below show the flow duration curves for the Mubuku and Nyawmabma watersheds.





Sediments

As the sediment samples were carried out before the strong rains in the rain season, it was assumed that the measured values are representative for the lower values in the sediment concentration duration curve. Following from this, the *a* parameter was assumed to be 5 for Mubuku 50 for Sebwe, and 10 for Nyamwamba. Please note that these are first-order approximations that cannot be used for absolute sediment load estimation. But given the focus on relative impacts of this study, this was found reasonable. More measurements are required during at least one year on a regular basis to be able to calibrate bot parameters of the equation.

Scenarios

The below table shows the parameter changes for each of the scenarios studied. The 0% implementation level corresponds to the baseline scenario.

		Implementation level					
Scenario	**Parameter**	**50%**	**25%**	**10%**	**5%**	**2%**	**0%**
Mulching	**RunResist**	3.5	2.3	1.5	1.3	1.1	1.0

	FlowDir	1.0	1.0	1.0	1.0	1.0	1.0
Agroforestry	**RunResist**	4.00	2.50	1.60	1.30	1.12	1.0
	FlowDir	0.74	0.78	0.87	0.92	0.95	1.0
Terracing	**RunResist**	6.0	3.5	2.0	1.5	1.2	1.0
	FlowDir	0.62	0.63	0.78	0.86	0.93	1.0

8 Annex III –Monitoring Database

Database setup

Central in the development of a PES scheme, is a database that includes the relevant datasets, is transparent to the involved parties, and that is in the base of setting up the agreements. A stakeholder-friendly, functional database was developed and designed to include the baseline hydrological and agronomic data.

The database includes various example reports. A tutorial was prepared that was used during the stakeholder validation workshop of the study. The tutorial explains how to build and modify reports and interpret the data, through several exercises and questions.

The Rwenzori Watersheds Database is developed in Microsoft Excel: a software program that most staff of stakeholders will have a minimum of familiarity with, and thus limiting the risk of non-adoption. The database is indexed, so users can access the different input tables through links.

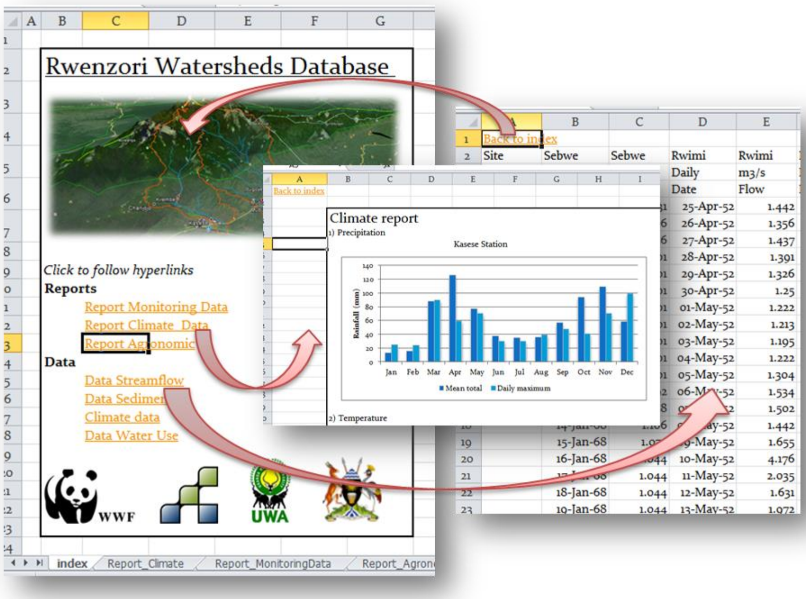


Figure 50. Screenshot of the Rwenzori Watersheds Database

Besides the data itself, the Excel-based database includes a few example reports. They are meant to be improved and adapted, depending on how the PES scheme development evolves and interests of stakeholders.

The timeseries datasets, have the following structure:

- First row links with index
- Second row: site names
- 3rd and 4th row: latitude and longitude (or UTM coordinates)
- 5th row: unit
- 6th row: variable name
- 7th row and below: data records

Below two examples:

	A	B	C	D	E	F	G	H	I
1	Back to index								
2	Site	Kasese							
3	Lat	0.18							
4	Lon	30.1							
5	Unit	Daily	mm	ºC	m/s	ºC	ºC	ºC	
6	Variable	Date	Rainfall	Dewpoint	Wind spe	Tmax	Tmin	Tavg	
7		07/01/1973		15.72222	1.234666	31.0	19.0	24.3	
8		16/01/1973	0		0.514444	23.0	18.0	20.7	
9		21/01/1973	0	15.77778	1.646221	32.0	17.0	26.0	
10		23/01/1973	0	14.27778	2.263554	32.0	10.0	23.0	
11		29/01/1973	0		514.3926	34.0	19.0	24.8	
12		[illegible]	0		[illegible]	[illegible]	[illegible]	[illegible]	

The datasets that are included (or should be in the future) in the database are:

- Precipitation from the following sources:
  - DWRM
  - UWA
  - GSOD
  - FEWS RFE
- Streamflow, from:
  - DWRM
  - WWF (current study)
- Water quality data, from:
  - UWA (not yet available)
  - WWF (current study)
- Water use, from:
  - Hydropower (not yet available)
  - Extractions for water supply
- Agronomic data (current study)

A short description of the currently available datasets is provided:

FEWS RFE. For Africa, a reliable satellite-based rainfall dataset is available, called RFE, provided by the Famine Early Warning Systems Network (FEWS). The latest version is 2.0 (Xie et al. (1997)) and provides accurate daily rainfall estimates for Africa on a spatial resolution of 0.1° (~10 km), and is one of the best rainfall products available for Africa. RFE 2.0 estimates rainfall using a two part merging process; first all satellite data are combined using the maximum likelihood estimation, and secondly Global Telecommunication System (GTS) data are used to remove bias. Period included in database: 2001-2014

DWRM. DWRM provided data for Kasese from an automated weather station. Data has gaps, and inconsistencies in rainfall data (unlikely low and high values for some years). Besides rainfall, temperature (avg, min, max), relative humidity, vapour pressure deficit, solar radiation, wind speed and wind direction is available. Period: 2004-2015

UWA. UWA has provided data for 4 stations on different elevations in the park. There are gaps, but period cover 2009 – 2015. Variables: rainfall, temperature, atmospheric pressure and humidity.

GSOD. Data from the Global Summary of the Day (GSOD) dataset for Kasese was included in the database. Period covers 1973 – 2014. Variables: rainfall, temperature, humidity, wind speed.

Historic streamflow. Daily streamflow records are made available by DWRM. There are periods with gaps, but period covers year 1954 -1984.

Current streamflow and water quality. Data on streamflow and water quality from current measurement campaign for this study is included, see for more details the report.

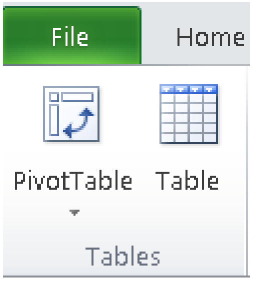
Agronomic survey. All data collected for agronomic survey is included.

Pivot tables

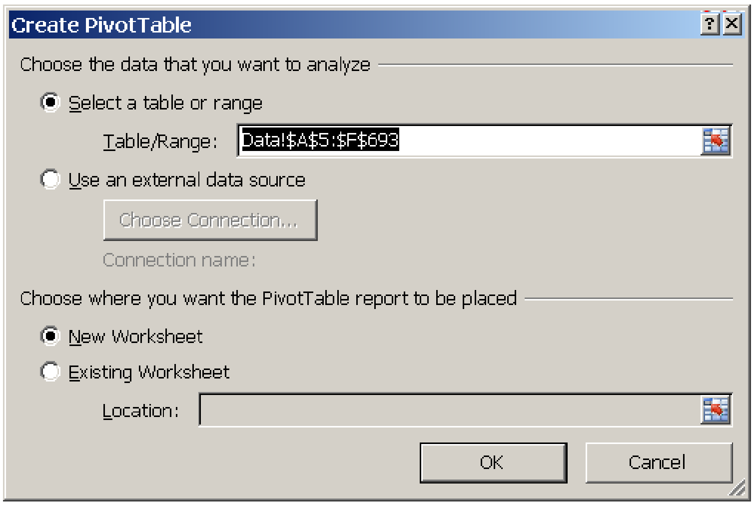
A PivotTable is a Microsoft Excel tool. In fact they are multidimensional databases (MDBs) that provide online analytical processing, or OLAP. This means they enable you to quickly summarize, cross-tabulate, and analyze large amounts of data. You can pivot, or rotate, rows and columns to see different summaries of the source data, filter the data, and drilldown to the details in the underlying source data.

To start your pivot table, follow these steps:

- Click on a cell in the data table.
- Click on the **Insert** menu and click the PivotTable button:



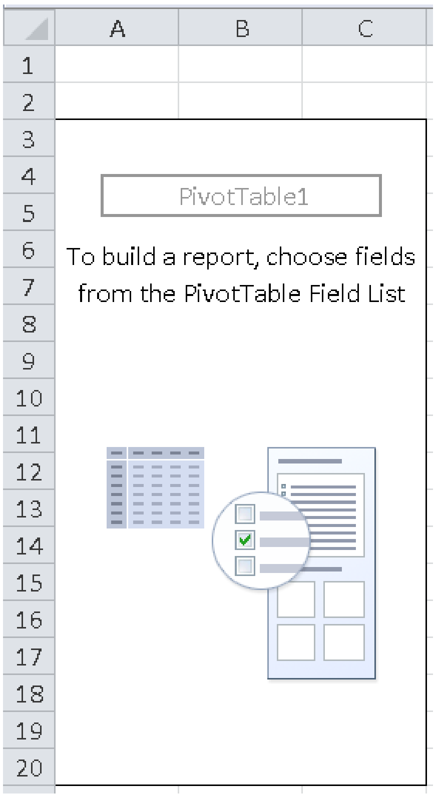
- The following dialog box will appear:



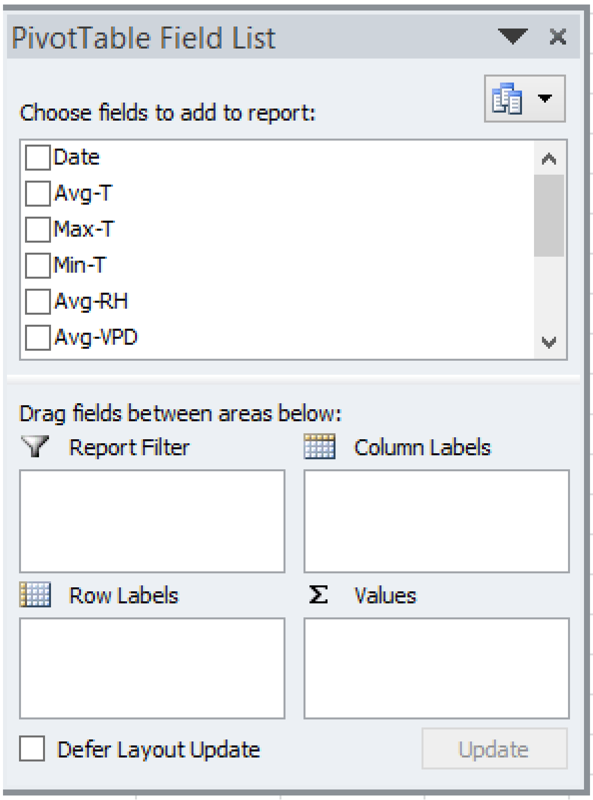
- Note that the **Table/Range** value will automatically reflect the data in your table (you can click in the field to change the Table/Range value if Excel guessed wrong).

- Also notice that you can choose where the new PivotTable should go. By default, Excel will suggest a **New Worksheet** but you can also choose a location in the same worksheet where the data appears
- In our case we will choose a location on one of the reporting worksheets. So a pivot table of climate data, we´ll locate in the Climate Reporting datasheet

To design your PivotTable layout, switch to the worksheet with your new Pivot Table. You'll notice three separate elements of the Pivot Table on the screen, starting with the **PivotTable report** itself:



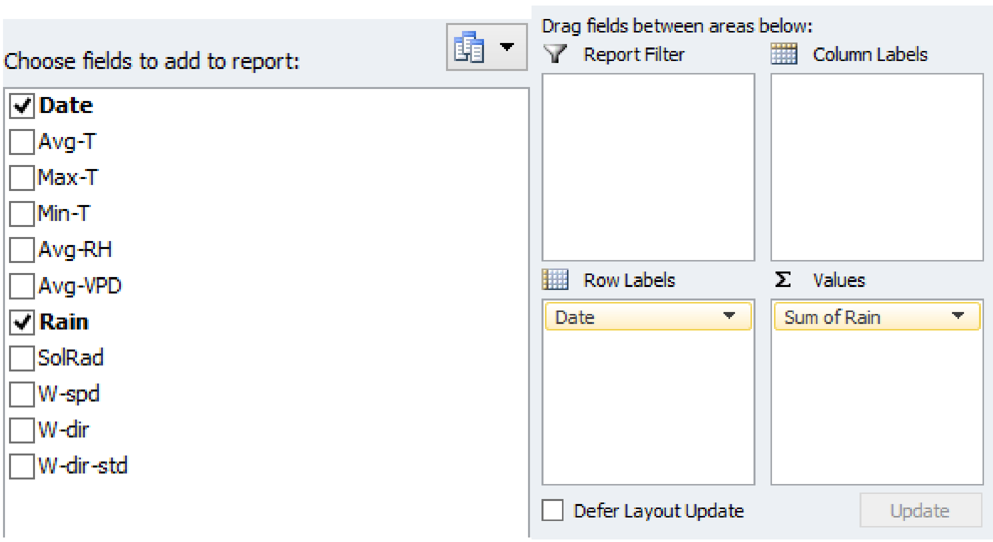
 Then you'll see the **Pivot Table Field List** and under that the **field layout area**. Note that it should show the column headings from your data table.



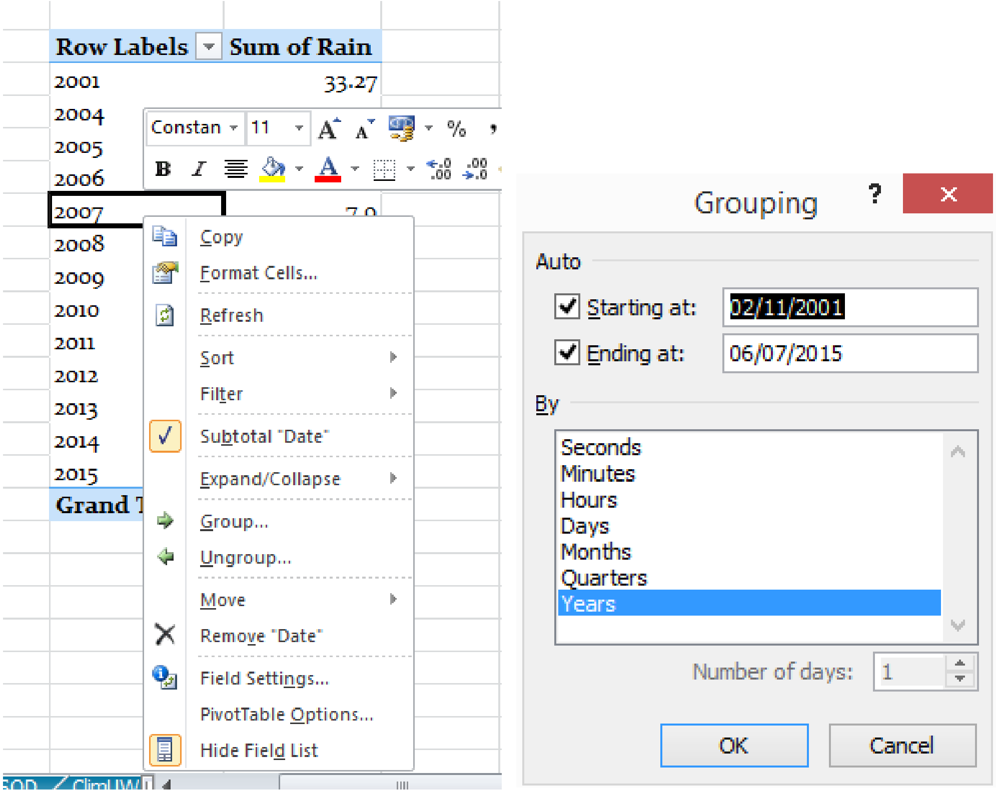
 To create the layout, you need to first select the fields you want in your table, and then place them in the correct location.

- You can check the boxes for the fields you want to include, and Excel will guess which area each field should be placed in. However, the Pivot Table is recalculated each time you check one of the boxes which can slow you down, especially if Excel places a field in the wrong place.
- Therefore, I recommend you drag and drop each field to the area you want it to be.

As an example, here are the Field List and the Field Layout area above with the fields in place to show a report with:



You can right-click and then click on group. After you group the dates in for example years.



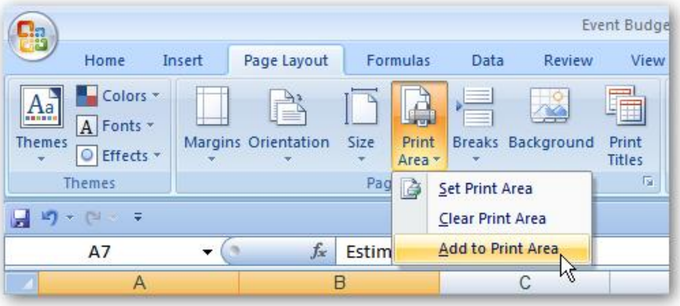
- The report that this generates looks like this:

Row Labels	Sum of Rain
2001	33.27
2004	373.9
2005	143
2006	127
2007	7.9
2008	703.5
2009	240.2
2010	244.8
2011	643
2012	9
2013	0
2014	0
2015	22.5
Grand Total	**2548.07**

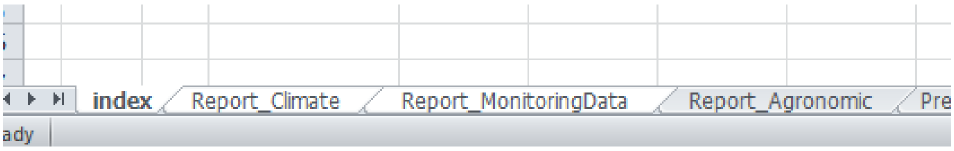
Save all reports as pdf

Follow these steps to generate a pdf with all reports:

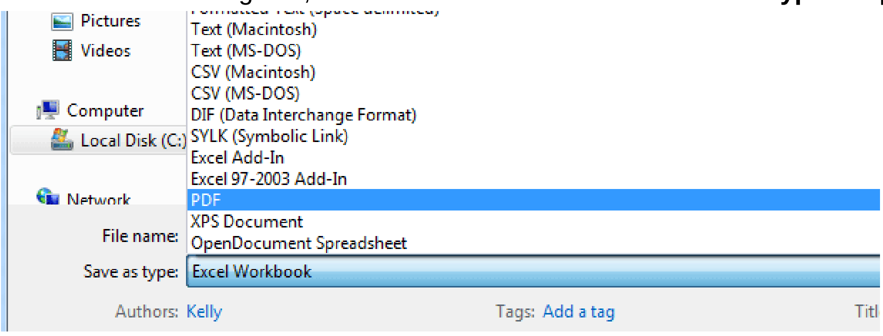
1. If necessary, adjust Print Area on the Layout tab



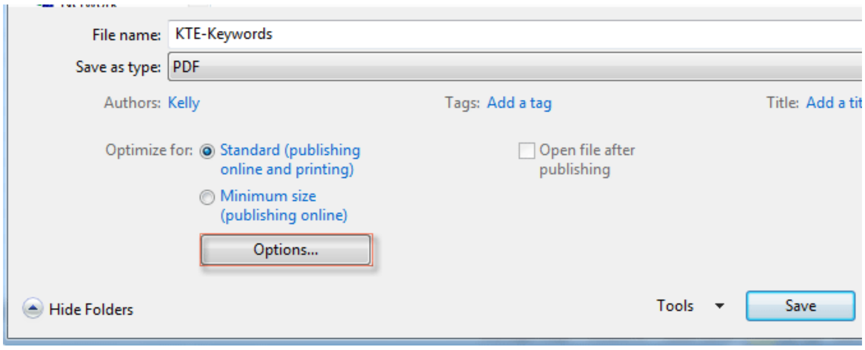
2. Select all the Reporting Worksheets, by holding Ctrl, and clicking the tabs of the worksheets



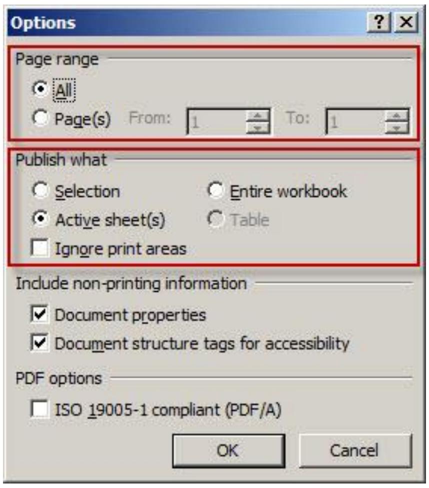
3. Click the **File** >> **Save as** in Excel 2010 or **Office button** >> **Save as** in Excel 2007.
4. In the Save As dialog box, select the **PDF** item from the **Save as type**: drop down list.



5. Click the **Options…** button at the bottom of Save As dialog box.



6. In the Options dialog box, check the **Active Sheets** option



7. Click **OK** to dismiss the dialog boxes.

Then you will see it saves all the active reporting sheets in a single PDF file.

9 Annex IV – Field sampling data

On-site sampled water quality data

SAMPLING PT	GPS POSITION	Elevation	Temp (Degs C)	PH(PH Units)	EC (Us/cm)	Turb(NTU)	DO(mg/l)	TDS (mg/l)	ORP(mv)	Total Coli	E-Coli
R-Nyamwamba	N00.23854 E029.97890	1754	15.86	6.84	22	10.4	15.73	15	278	182	21
Mulyambuli Stream	N00.23739 E029.97840	1751	17.33	7.79	94	9.8	10.71	61	256	312	35
R-Nyamwamba (At Masule Bridge)	N00.22112 E029.99787	1498	16.32	7.19	34	7.2	7.56	22	264	208	34
R Nyamwamba (Down stream near Kiwa Hot springs)	N00.19282 E030.05682	1068	20.65	7.31	83	19.4	9.8	50	289	5422	316
R-Nyamwamba (At Railway Bridge)	N00.18551 E030.11395	949	25.37	7.36	105	98.5	10.04	68	258	611	412
Hyoho Stream(Tributory to R-Mubuku)	N00.35981 E030.01406	1885	17.26	7.84	67	3	8.12	44	277	356	86
R-Mubuku (At park entry)	N00.36068 E030.02407	1757	16.69	7.64	46	5.7	11.22	34	288	26	7
R-Mubuku (At Kilembe Dam)	N00.34662 E030.03910	1616	17.86	7.69	51	0.7	13.67	31	260		
R-Mubuku (Below Kilembe Dam)	N00.34575 E030.04302	1593	16.74	7.6	52	4.4	10.11	34	288	127	342
R-Mubuku (Before Bukoye Power Dam)	N00.33708 E030.07286	1432	16.26	7.27	41	9	11.31	26	233	70	10
Kithakena	N00.34687 E030.07750	1423	18.79	7.73	61	7.3	12.6	40	266	540	430
R-Mubuku (Before Dam near Mugoya Power)	N00.30878 E030.10104	1248	19.36	7.69	43	10.5	7.79	28	290	42	20
R-Mubuku -Rwankingi (Behind a Prumary School)	N00.28052 E030.11177	1150	21.62	7.14	80	3.1	15.53	44	250	436	120
R-Mubuku Below KCCL Hydropower outflow Channel	N00.25405 E030.15502	992	21.9	7.46	56	7.7	6.87	34	262	562	240
R Sebwe (Isumba 1 Village, Bugoye Parish)	N00.30027 E030.05610	1459	16.79	7.2	28	12	14.6	18	245	689	80
R Sebwe (Above the bridge at the road to F-Portal)	N00.25501 E030.11585	1090	22.02	7.68	62	36.4	6.66	40	264	615	186

Water quality data from laboratory analysis

SAMPLING PT	Lab No.	T-Hard	T-Alk	NO3	NO2	T-Iron	SO4	F	COD	BOD	tss
R-Nyamwamba	E27122	10.5	7.6	0.7	0.003	0.39	<2	0.18	<20	0.69	<1
Mulyambuli Stream	E27123	36	24	1.8	0.003	0.4	22	0.14	<20	0.35	9
R-Nyamwamba (At Masule Bridge)	E27124	14.2	11.6	1.4	0.005	0.25	<2	0.15	<20	0.63	1
R Nyamwamba (Down stream near Kiwa Hot springs)	E27125	33.9	16.8	1.3	0.005	1.25	25	0.2	<20	0.45	13
R-Nyamwamba (At Railway Bridge)	E27126	27	18.2	0.9	0.002	0.94	29	0.16	<20	0.57	7
Hyoho Stream(Tributory to R-Mubuku)	E27127	30.5	27.6	1.8	0.006	0.44	3	0.11	<20	0.27	7
R-Mubuku (At park entry)	E27128	24.6	15	1.3	0.005	0.34	10	0.12	<20	0.15	1
R-Mubuku (At Kilembe Dam)	E27129	26.8	17.6	1	0.008	0.22	9	0.11	<20	0.18	1
R-Mubuku (Below Kilembe Dam)	E27130										
R-Mubuku (Before Bukoye Power Dam)	E27131	21.4	14.4	0.7	0.005	0.29	<2	0.04	<20	0.18	1
Kithakena	E27132	24.7	26.2	1.2	0.005	0.32	<2	0.04	<20	0.37	2
R-Mubuku (Before Dam near Mugoya Power)	E27133	22.3	14.6	0.9	0.005	0.29	<2	0.04	<20	0.29	5
R-Mubuku -Rwankingi (Behind a Prumary School)	E27134	25	19.4	1.3	0.002	0.45	<2	0.05	<20	0.18	7
R-Mubuku Below KCCL Hydropower outflow Channel	E27135	76	18	2.2	0.002	0.66	10	0.04	<20	0.95	4
R Sebwe (Isumba 1 Village, Bugoye Parish)	E27136	12.8	9.6	1.5	0.003	0.35	<2	0.08	<20	0.59	30
R Sebwe (Above the bridge at the road to F-Portal)	E27137	19.2	21.6	1.7	0.004	0.87	<2	0.07	<20	0.34	1.5

Streamflow data

Date	River	Location	Northings	Eastings	Discharge	Mean Vel.	Width	Area	Mean Deph
					m^3/s	m/s	m	m^2	m
22/10/2015	Kithakena	Mubuku tributary	0.3469	30.078	0.762	0.559	6.50	1.36	0.21
20/10/2015	Kyoho	Mubuku tributary	0.359910	30.014	0.269	0.438	3.80	0.62	0.16
22/10/2015	Mubuku	after Bugoye power station abstraction point	0.3368	30.073	0.675	0.327	11.90	2.06	0.17
21/10/2015	Mubuku	at Kilembe intake point	0.3466	30.039	5.08	1.777	16.40	2.86	0.17
22/10/2015	Mubuku	before Bugoye power station abstraction point	0.3371	30.073	10.547	1.204	22.50	8.76	0.39
21/10/2015	Mubuku	below kilembe abstraction point	0.3458	30.043	6.408	1.053	15.20	6.08	0.40
21/10/2015	Mubuku	near part city	0.3371	30.073	2.349	1.326	9.00	1.77	0.19
23/10/2015	Mubuku	Kwakingi	0.2805	30.112	6.494	0.942	17.65	6.90	0.39
22/10/2015	Mubuku		0.308	30.101	3.421	0.588	22.60	5.82	0.26
19/10/2015	Mulyambuli		0.2374	29.978	0.348	0.401	2.80	0.87	0.31
20/10/2015	Nyamwamba	near kiwa hotspring	0.1928	30.057	3.481	0.674	12.80	5.17	0.40
20/10/2015	Nyamwamba	below masule bridge	0.2239	29.997	4.389	0.914	13.90	4.80	0.35
20/10/2016	Nyamwamba	bridge			4.241	0.525	22.60	8.08	0.36
19/10/2015	Nyamwamba	Above railway crossing	0.1855	30.114	1.654	0.562	7.79	2.94	0.38
24/10/2015	Sebwe	above bridge Kasese- F/Portal Rd	0.0255	30.116	1.511	0.608	7.80	2.49	0.32
24/10/2015	Sebwe	near park boundary, Bugoye village	0.3003	30.056	1.609	0.517	10.20	3.11	0.30
24/10/2015	Sebwe	Below irrigation dam	0.2415	30.124	0.384	0.298	6.45	1.28	0.20

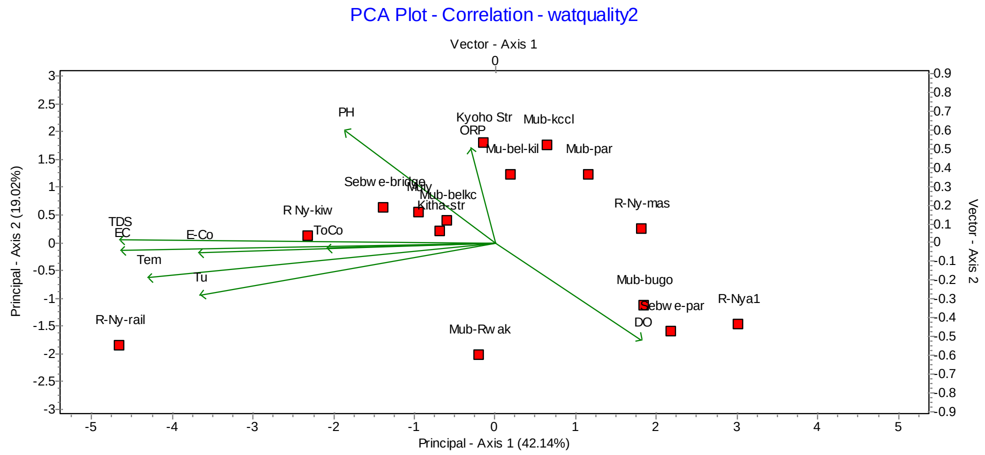


Figure III.1 Spatial variation in water quality variables in the sampled sites

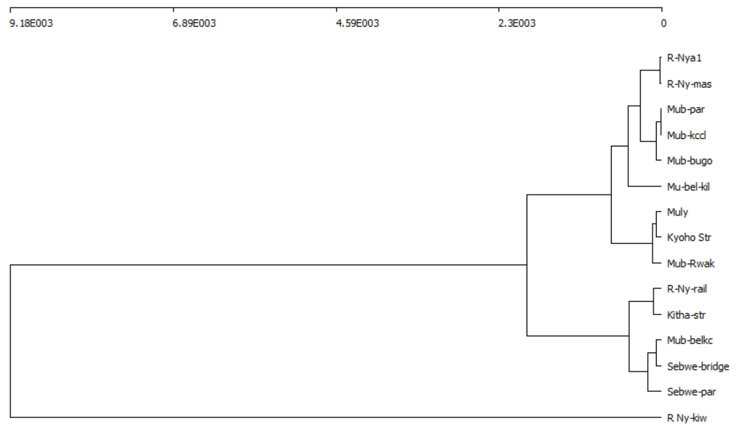


Figure III.2 Cluster analysis showing segregation of sample sites based on water quality measures.

10 Annex V – Guiding questions Focus Group discussions

The following questions were used to guide the Focus Group Discussions:

- What are the important land use types differentiated by the community and the main water resources available and used by the community in the study area?
- What are the main livelihood / production activities during the i) rainy and ii) dry seasons (include the main things people do for subsistence and to generate income)?
- Agricultural Production activities: farm practices, inputs use and frequency, availability of extension services, water use for irrigation, erosion (types, state, extent, severity), major causes of degradation, control interventions.
- What are the main natural resources that the community uses for production / livelihoods? (e.g. grazing land, fuel wood, timber, medicinal plants, dry season water sources etc.).
- What are the important types of land degradation in the area? For each distinct type: What do you consider are the main causes? What are the main impacts? What are the changes in the last 10 years, in terms of type, extent and severity?
    - **Soil:** Is soil erosion occurring or are there other types of soil degradation? What are the main causes? What indicators do the locals use to describe soil erosion / degradation (e.g. loss of fertility, soil loss, gully formation (active / under control), build, sediment load etc.)
    - **Vegetation**: Is deforestation occurring in the study area? Is this exploitation for local use, for transport to cities or both? Has it increased? What is the main local source of fuel for cooking (and heating)? Have the cover and / or species composition and quality of vegetation been increasing or diminishing? Have the abundance (number of plants) and richness (number of species) of i) palatable species for livestock or ii) invasive species increased or decreased in the area? Since when have the changes taken place? What are the causes? What conservation / management practices are used? Depending on the responses further questions can be asked for example: Are fires a serious problem? Has the frequency and severity increased – or decreased? Is burning used for pasture management and / or pest control? What are its effects?
    - **Water**: What changes (over the last 10-20 years?) have there been changes in the amount and quality of water resources in the study area? (e.g. trends in rainfall amounts and seasonal distribution; drying up of water points, changes in levels of water in wells and boreholes; changes in river / stream flow, changes in water quality (salinity, pollution)). Is water used for irrigation and where is it sourced (e.g. rainwater harvesting, streams / rivers or wells / boreholes)? What crops are irrigated, when (all the growing season or only during specific critical period) and by whom? Do community members pay for water and under what circumstances
- Has the study area experienced i) drought, ii) flooding or any other extreme weather event (e.g. intense storms) in the last 10 years? Is this normal or exceptional?
- What are the strategies and coping mechanisms adopted i) during drought or unusual dry years or ii) to reduce risk of flooding?
- Are there any conflicts in relation to land and water uses in the area?

- What are the main livelihood problems (i.e. serious / long term) / difficulties (less serious / short term) faced by rural households (food insecurity, poverty, access to resources, access to markets)?
- Are there successful areas where land degradation control (i.e. conservation, restoration and or improvement of land resources) has been achieved? What were the main sustainable land management (SLM) practices or measures (policies, legislation, bye-laws etc.) to prevent land degradation that were implemented in specific land use systems / types? Were they aimed: i) to improve or restore the productive capacity of the land (e.g. soil fertility, use of water); or ii) for conservation / protection of resources (soil, water, vegetation, wildlife, biodiversity). Indicate for each whether they are the result of an external intervention or a local / traditional practice.
- If possible, identify any interventions that have gone beyond a focus on productivity to address wider ecosystem services (e.g. water catchment / supply, carbon sequestration, reduced greenhouse gas emissions, pest and disease regulation, protection of biodiversity and aesthetic landscape values etc.). What practices were used and what was achieved?

11 Annex VI – Form used for Agronomic Transects

GPS location	N:……………………… E……………………….. Alt:……………………..
Average slope	1. Very steep (45+ degrees) 2. Steep (35 – 45degree) 3. Extreme slope (24 – 35degree) 4. Strong slope (8.5 – 24degree) 5. Moderate slope (5 – 8.5) 6. Gentle slope (1.1 – 5degree) 7. Nearly level (below) 1.1 degree
Land use types	1. Perenial – Single stand 2. Perenial – Intercrop 3. Annual – Single 4. Annual Intercrop 5. Fallow 6. Woodlot 7. Natural grassland 8. Natural forest 9. Grazing area 10.
Crop type: Dominant crop, others	Dominant crop: 1. Coffee 2. Banana 3. Cassava 4. Beans 5. Potato 6. Sorghum 7. Sweetpotato Other crops, % 1. Coffee 2. Banana 3. Cassava 4. Beans 5. Ground nuts 6. Cucumber 7. Sugarcane 8. Avocado 9. Maize 10. Yam 11. Guava 12. Pineapple 13. Eggplant 14. Mango

Evidence of pests & diseases *(yellowing, blemishes, others)*	1. Banana bacterial wilt 2. Cassava mosaic disease 3. Fusarium wilt 4. Coffee leaf rust 5. Coffee berry disease 6. Mineral deficiency 7. Black sigatoka 8. Banana weevil 9. Leaf miner 10. Weeds 11. Leaf roll virus
Soil /description - *Type, Colour*	Type: 1. Sandy 2. Sandy loam 3. Sandy clay 4. Silty clay 5. Silty loam 6. Clay loam 7. Loam 8. Clay 9. Sandy-clay-loam 10. Silty-clay-loam 11. Gravel/stony 12. Murrum **Color:** 1. Black 2. Dark brown 3. Brown 4. Grey 5. Dark greyreddish-brown
Natural vegetation *Tree and grass types*	**Tree type** 1. Albizia 2. Accacia 3. Markemia 4. Eucalyptus 5. Calliandra 6. Erythrina 7. Bamboo 8. Ficus 9. Lantana 10. Grieviellia 11. Maesopsis 12. Moringa 13. Vernonia 14. *Kaakororo* 15. *Omuhanga* 16. *Amatojo* 17. *Omunyinya*

	Grass type 1. Cymbopogan 2. Digitaria 3. Hyperhenia 4. Setalia 5. Napier 6. Cynodon 7. Lemon grass 8. Imperata 9. Panicum 10. Silverleaf 11. *omuhihi*
Deliberate efforts for improved crop management practices	1. Spacing 2. Weeding 3. Line planting 4. Intercropiing
Land degradation features , signs of erosion, erosion types, state, extent and severity	**Types** 1. Declined fertility 2. Soil erosion 3. Reduced productivity 4. Landslides 5. Over cropping 6. Tree cutting 7. Bush, trash and charcoal burning 8. Degrading river banks 9. Cultivation of steep slopes 10. Bare/exposed soil 11. Tree cutting 12. Boulder deposits 13. Wetland draining 14. Poor drainage

	Soil erosion type 1. Splash 2. Sheet wash 3. Rill 4. Gully 5. Landslide **Extent** 1. widespread, 2. moderate, 3. localised, 4. negligible) **State** 1. active, 2. stabilised, 3. stable, 4. negligible) **Severity** 1. Extreme, 2. severe, 3. moderate, 4. low 5.
Land management / soil and water conservation / restoration measures	1. mulching, 2. terrace, 3. soak pits, 4. trenches, 5. grass strips, 6. agro-forestry trees and shrubs, 7. zero tillage, 8. cover crops 9. fallowing 10. Tree planting 11. Large planting holes

12 Annex VII – Bentthic macroinvertebrate relative abundance of the sampled sites

Family / Site	Nyam-par	Nyam-hots	Nyam-masb	Mub-abovkil	Mubuku-par	Kyoho-par	Mub -bel-bug	Mub-abovbug	Mub-rwak-sc	Mub-bel-KC	R. Sebwe (belowthe park boundary)	Seb-bel-apr (at irrigation scheme)	Seb-ab- bri)
Baetidae	54	0	29	3	6	24	60	16	20	20	34	36	68
Caenidae	0	0	0	0	0	0	0	5	2	0	2	3	2
Lepitophlebidae	0	0	0	0	0	4	0	1	0	0	0	1	0
Heptageniidae	0	0	0	0	0	2	3	11	8	23	2	15	36
Tricorythidae	0	0	0	0	0	0	0	0	0	0	0	0	1
Perlidae	53	0	1	58	14	26	0	0	0	0	16	0	0
Hydropsychidae	6	0	44	30	16	134	2	7	7	2	8	3	0
Philopotamidae	1	0	0	0	0	0	0	0	0	0	0	0	0
Clamoceratidae	0	0	0	1	0	0	0	0	0	0	0	0	0
Lepidostomatidae	7	0	8	5	5	12	0	5	0	0	17	0	0
Leptoceriidae	0	0	0	0	2	0	0	0	0	0	1	0	0
Libellulidae	0	2	1	1	0	0	0	0	0	0	1	0	0
Coenagrionidae	0	0	0	0	0	0	0	0	1	0	0	0	0
Gomphidae	0	0	0	0	0	0	0	0	1	0	0	0	0
Elmidae	0	0	0	3	6	1	0	0	1	0	0	0	0
Dytiscidae	0	3	0	0	0	0	0	5	0	0	0	0	0
Gyrinidae	0	3	0	0	0	0	0	0	1	0	0	0	0
Psephenidae	0	0	0	0	0	2	0	0	0	0	0	0	0
Scirtidae	9	0	7	0	1	0	0	0	0	0	0	0	0
Athericidae	2	0	1	0	0	0	0	1	0	0	2	0	0
Ceratopogonidae	0	0	0	0	0	0	0	0	1	0	1	0	0
Chironomidae	0	0	1	0	0	0	1	0	0	0	1	0	1
Simulidae	16	0	622	0	0	14	3	6	0	0	0	4	0
Tipulidae	0	0	0	3	0	4	0	1	0	0	4	0	0
Delichopodidae	0	0	0	0	0	0	0	0	0	0	1	0	0
Naucoridae	0	0	0	0	0	0	0	0	2	1	0	0	0
Planariidae	0	0	0	1	0	1	2	0	0	0	0	0	0
Oligochaeta	0	0	2	0	0	8	0	0	1	0	2	1	0