SEDIMENT FINGERPRINTING IN SBEeya CATCHMENT:

Identifying the potential sources of river sedimentation

Report by BirdLife International,
With the technical support from Rwanda Water and Forestry Authority and Yale University

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LIST OF ABBREVIATIONS

A.b.s.l: Above Sea Level
CRAG: Climate Resilient Altitudinal Gradients
GIS: Geographical Information System
MASS: Modern Applied Statistics with S
MCMC: Markov Chain Monte Carlo
MixSIAR: Mixing model – Stable Isotope Analysis in R
MoE: Ministry of Environment
RNRA: Rwanda Natural Resources Authority (now Rwanda Water and Forestry Authority)
RSB: Rwanda Standards Board
RWFA: Rwanda Water and Forestry Authority
SSG: Site Support Group
W4GR: Water for Growth Rwanda
XRS: X-Ray Spectrometry
ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

This report describes the process and results from the sediment fingerprinting technique, which was carried out in Sebeya Catchment of Rwanda, from October 2017 to August 2018. Based on different physical and geochemical characteristics of sediment sources in a targeted catchment, sediment fingerprinting is useful to determine the amounts of the river’s suspended sediments that originate from a particular source within the catchment. The bottom-line of conducting this sediment fingerprinting study was to identify potential erosion hotspots, and hence sites contributing to the sedimentation of Sebeya River, part of the large Lake Kivu and Rusizi River basins. Both erosion and sedimentation are listed among the climate change impacts, which have been predicted in the African Great Lakes Region, and are already happening now. In Sebeya Catchment, the erosion risk was proven to be critical; this resulting from a combination of heavy rainfall during rainy seasons, steep slopes not covered with vegetation, and unsustainable land use practices.

Since Sebeya River system plays a major role in hydropower production, water provision to the catchment’s inhabitants and animals and provides the moist suitable soil for agriculture; it is crucial to understand processes behind the river pollution and develop measures for its protection. With this research, sites contributing to erosion and sedimentation were pinpointed and this is a starting point to guide on-the-ground climate change resilience actions for local communities in the catchment. All the activities involved representatives of two selected Site Support Groups (SSGs): one from a mining and another from a farming cooperative in Sebeya Catchment.

First, the data on soil and sediment were collected following a study design using available GIS layers of geology, catchment drainage and land use/land cover among others. Secondly, the X-Ray Spectrometry was used to determine the concentrations of a suite of elements in the soils and suspended sediment samples. Thirdly, the laboratory results formed inputs to the statistical analysis using a Bayesian mixing model. The latter successfully provided the contribution to Sebeya River sedimentation, by geological units and sub-catchments. The model results could however be improved if several and repeated sediment sampling is carried out in the catchment and considering the seasonal variation. Mapping of prioritization areas was finally done to categorize zones in the catchment into three important levels corresponding to high contribution, medium contribution, and low contribution to the river sedimentation. More interestingly, some locations could be classified as having a very low contribution to river sedimentation; to mean these might be Key Biodiversity Areas, protected slopes where forest is planted or sustainable erosion control measures are in place.

The produced map was validated with a fieldwork at some selected locations from each category either level 1, 2 or 3. At the same time, brainstorming on possible climate change interventions was done, through getting quick ideas from members of SSGs and field observation. There are on-going initiatives on land and ecosystem rehabilitation in Sebeya Catchment, to cite some: the Water for Growth Rwanda, the Landscape Approach to Forest Restoration and Conservation, and a number of long-term projects implemented under the Rwanda Ministry of Agriculture. BirdLife International will also contribute to these existing interventions, especially incorporating community consultation and carrying out climate change vulnerability assessments for local communities in few selected sites of Sebeya Catchment.
1. BACKGROUND OF SEBEYA AND EROSION RISK IN THE CATCHMENT

This section provides a brief introduction to Sebeya, and links the catchment characteristics to the erosion and sedimentation risk. Most of the maps presented here show locations where soil and sediment were sampled for sediment fingerprinting. The details on Sebeya Catchment can be found in the catchment plan developed by the Water for Growth Rwanda (W4GR), a four-year, joint Rwanda-Netherlands initiative aiming to improve effective management of Rwanda’s water resources.

Sebeya Catchment is located in the north western Rwanda, and is shared between four districts: Rubavu, Rutsiro, Ngororero and Nyabihu (Figure 1). The catchment area is approximately 360 km$^2$, and its water empties into Lake Kivu.

![Figure 1: Location of Sebeya Catchment in the north western Rwanda, there are 3 more catchments of this subdivision. The main river Sebeya gets water from different tributaries and it empties into Lake Kivu. Map from W4GR (2018)](image)

1.1 Topography, rainfall and land use/land cover

A recent study by the Rwanda Ministry of Environment has shown a very high risk of erosion in the north western Rwanda, covering areas of Sebeya Catchment (MoE, 2018). The Sebeya catchment is considered as a catchment with high erodibility factor. This is mainly because the rainfall distribution in the catchment varies between 1,200 to 1,700 mm per year, indicating very wet conditions. The catchment is also characterised by steep slopes and complex topography (abrupt changes of altitude on small distances), which varies between 1,462 to 2,902 m a.b.s.l (Figure 2).

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1 http://www.water.rw/publication/
In addition, the major land use and land cover classes in the catchment include cattle grazing, agriculture and forest plantations. There are practices to support green agriculture and mining, but still several cases of unsustainable mining and agriculture are happening, even along Sebeya River. Therefore, during heavy rainfall, sediments are washed into the river causing terrible sedimentation.

Figure 2: Main characteristics of Sebeya Catchment: administrative boundaries, topography, annual rainfall and land use/land cover maps. For the land use/land cover, it is important to note that the dense forest patch in the south western part constitutes the remaining of natural Gishwati forest, a Key Biodiversity Area.
1.2 Soils and geology

The major geological formation in the Sebeya Catchment are the Butare complex (Bu) and volcanic rocks of Virunga Mountains (B) formations (see Table 1 for details). The latter, comprise a complex network of caves and a thin layer of soil susceptible to runoff erosion if not properly managed. The soil classes are predominantly nitosol, acricol, alisol, lixisol class found throughout the catchment area, as these are pockets of ferralsols and cambisol and andosols (RNRA, 2015). Infiltration rates of these soils are generally high, except for the case for the clay and mineral soils on flat topography encountered in the catchment. The combination of the geological formation and soil data characterises the Sebeya river catchment as a fragile ecosystem susceptible to heavy erosion (MoE, 2018).

Table 1: Some descriptions of the geological types in Sebeya Catchment. Descriptions need to be expanded with further research.

<table>
<thead>
<tr>
<th>Geological class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granites indifférenciés</td>
<td>All the terrains with granitical lithology in the Butare complex</td>
</tr>
<tr>
<td>Bu</td>
<td>Butare complex. Alternation of granites, gneissic granites, quartzitic metasediments, micaschist and amphibolites</td>
</tr>
<tr>
<td>B</td>
<td>Volcanic rocks of Birunga mountains (undifferentiated)</td>
</tr>
<tr>
<td>Ho</td>
<td>Alluvial of valley, lower &amp; middle terraces, cones of dejection. Holocene &amp; Pleistocene undifferentiated</td>
</tr>
<tr>
<td>Uw/ Cr</td>
<td>Uwinka formation (500 m). Pelitical dominance: bicolor-banded quartzophyllite, generally black/light gray or black/red. Cyurugeyo superformation (1,100-1,500m). Pelitical mountain peak (Kibuye formation) finely laminated with gray quartzophyllite</td>
</tr>
<tr>
<td>Nw</td>
<td>Nyungwe formation (200-400 m). Areno-pelitical: centimetric to metric sequentiel alternation of red quartzite and quartzophyllite to black phylite; levels of probable volcanic heritage</td>
</tr>
</tbody>
</table>
The population density and poverty rates, some descriptions on climate change, hydrology, amount of water, water balance, water quality, economic activities and infrastructure, catchment issues and opportunities: all these points have been detailed in the catchment plan, developed by the W4GR and can be downloaded from here. Also, a team of researchers (Seimon, Ingram, & Watson, 2012) developed models showing predictions of climate change in the African Great Lakes Region, including the Kivu-Rusizi basins.

Since the Sebeya Catchment is prone to erosion and the river experiences much sediment loads; which negatively affect the hydropower production, water consumption and irrigation, a sediment fingerprinting study was conducted; to identify locations contributing much to erosion rates and hence river sedimentation. The results inform the government, land management and conservation entities, for planning measures to reduce the amounts of sediment load into Sebeya River.

2. MIXING MODEL – PRIOR TO IDENTIFYING EROSION HOTSPOTS

BirdLife conducted sediment fingerprinting, as part of the long-term project on “building climate change resilience for local communities in the Lake Kivu and Rusizi River basins – CRAG”. The sediment fingerprinting has been successfully completed in the Nyabarongo Upper Catchment and recommendations can potentially guide land rehabilitation initiatives in the catchment.

This technique was also used by Dutton et al. (2013) to identify sediment sources in the Mara River basin in Kenya. BirdLife’s sediment fingerprinting study relied on suspended sediments from the river and soils on the land; and the results are comparable to theoretical frameworks and early studies on erosion risk in Rwanda.
All the activities were introduced to the relevant district authorities and local community groups were mobilised to be engaged as Site Support Groups (SSGs). The idea is to have communities understand the initial project activities, since they will be the main beneficiaries of on-the-ground climate change interventions.

2.1 What is sediment fingerprinting?

This involves a statistical comparison of the chemical composition of suspended sediments in rivers with the composition of elements of soils that constitute various geological types in a given catchment. The following are major steps to consider when carrying out sediment fingerprinting:

i. Collection of samples representing a range of possible sediment sources (“source samples”)
ii. Collection of one or more receiving-water samples, for which the source of sediment is to be determined (“downstream samples”)
iii. Analysis of both types of samples for a variety of potential tracer properties
iv. Statistical analysis of the potential tracer properties to determine which ones are able to reliably discriminate between the potential sources
v. Statistical apportioning of downstream sediment to the various potential sources using a mixing model.

The following diagram also highlights steps from sediment fingerprinting to climate change interventions.

Figure 4: Sediment fingerprinting study design, with results that feed into climate change interventions
2.2 Data collection for sediment fingerprinting

Two types of source samples were collected: soils and suspended sediments. Sampling of sediment was based on the drainage, local knowledge and catchment boundary, while soils were collected following the geological units, catchment boundary and land use types.

2.2.1 Trapping of sediments
- Use a water bottle to collect water at 4-5 m from the confluence of the main river and its tributary.
- For big tributaries (e.g. Pfunda of Sebeya), also consider sampling water at the confluence with the stream affluent.
- Measure 200 ml using a graduated cylinder and start the water filtration using an apparatus.
- Keep manipulating, and wait until all the water passes through the filter membrane (Nylon polyamide, pore size: 0.45 μm and diameter: Ø 47 mm).
- Sediments remain on the top of the filter membrane.
- Carefully remove the filter membrane and deposit into a well labelled petri-dish.
- The labels include the name of the catchment, tributary or stream, date of sample collection and district.
- Store each petri-dish in a big sample container (preferably plastic).
- Use the water battery to clean the equipment after filtration.
- Sediments were trapped three times at the same locations. This basically allows comparison of sediment load based on seasons (e.g. heavy rain vs slight rain or dry season).

Demonstrating community members the process of water filtration, to retain sediments on a filter membrane. The water was collected at 4-5 m from the confluence of Sebeya and its tributaries.
2.2.2 Collection of soil samples

- Follow each GPS point calculated with ArcMap 10.4
- At the sample collection location, dig up to 20 cm and collect a small amount of soil in a radius of 10 meters as illustrated on Figure 5
- No plastic material should be used for digging and collecting the sample. This is to avoid any risk of sample contamination and interference with metals to be traced from the sample
- For each geology, collect 5 samples, considering different land uses
- Soil samples were stored in a well labelled plastic bag. The label includes the catchment name, sample date, geology and sample number, district and sector.

![Figure 5: At each location, a composite soil sample was collected following this sketch](image)

2.2.3 Downstream samples

Downstream samples were taken as suspended sediment samples on filter papers in accordance with the procedures detailed above. These samples were taken at the outlet of Sebeya River Catchment.

![Sebeya water flowing into Lake Kivu in Rubavu District (place known as tam tam): Sebeya River receives water from different affluent and finally empties into Lake Kivu](image)
2.3 Laboratory analysis – chemical composition of soil and sediment samples

The analysis to determine the chemical composition using the X-Ray Spectrometry was carried out at Rwanda Standards Board (RSB). The laboratory results show the chemical composition of each targeted element (Annex 1) and they constitute inputs to the mixing model which is run using a programming language.

2.4 Catchment conceptualization

The conceptualization of a given catchment for the purpose of sediment fingerprinting consists of delineating the catchment into sub-catchments following the sediment sampling locations, which are set in such a way to enable determining the contribution of different sub-catchments within the system and how they build up together up to the catchment main outlet.

For the case of Sebeya Catchment, this exercise was carried out using the ArcGIS software and resulted in a delineation of 15 sub-catchments for which sediment sources were analyzed. These sub-catchments show the hydrological connectivity, which is of prime importance for sediment fingerprinting analysis (Figure 6). This connection guides the distribution and amount of sediment load in the river, depending on the upstream contribution (mostly related to anthropogenic activities). The sediment sampling was done on the Sebeya River affluent on either side (with collection point located upstream the confluence with the main river). As a result, all major affluent were monitored and a corridor was left as the collection area of all contribution all the way up to the outlet of the Sebeya River. In this way, each delineated sub-catchment was isolated and its contribution could be explicitly estimated from the statistical analysis.

![Figure 6: Sebeya River Catchment conceptualization](image-url)
2.5 Statistical analysis

All statistical analyses were done in R 3.5.1; most of the modelling procedures are described in Stock et al., (2018). Models were ran independently for each possible combination of geologic sources. Models were also ran for each combination of sub-catchments present that could be used as a potential sources. For Rwankuba, Kadobogo and Mubuga, the model could not be run for each of these sub-catchments, because either only one geological class covers the sub-catchment or there was only one sampling campaign done.

The Kruskal-Wallis H test was first used to identify tracers that showed significant differences between source types (kruskal.test function) (Kruskal & Wallis, 2016). A default p-value of 0.05 was used to determine significance. For several of the models, the default p-value did not provide enough tracers for use in the mixing model, so the p-value was adjusted up in 0.05 increments until a minimum of three tracers were identified that could be used in the mixing model. The identification and use of tracers using higher p-values from the Kruskal-Wallis test ultimately will be reflected in the greater 95% confidence intervals in the mixing model.

A step-wise discriminant function analysis based on the minimization of Wilks’ lambda was then used to determine which parameters were capable of discriminating between source types (greedy.wilks function in the klaR package and the lda function in the MASS package). A jackknifed discriminant function analysis was also used to assess the discriminatory power of the tracers through a cross-validation procedure (lda function in the MASS package). With the jackknifed procedure, the discriminant function analysis is run multiple times, leaving a different sample out each time. The procedure then provides a value of the success in the reclassification of the source samples that is often more conservative than a discriminant function analysis utilizing all source samples (Bordcard et al., 2011).

Parameters identified as useful by the Kruskal-Wallis H test and verified with the discriminant function analysis were then examined to ensure that the tracer values exhibited by the downstream samples were within the range of values presented by the upstream samples.

A mixing model with Bayesian Inference was used to determine the likely sources of sediments. The MixSIAR mixing model was originally developed for inferring diet composition from stable isotope analysis of consumers and sources (Stock et al., 2018). MixSIAR allows for all sources of uncertainty to be propagated through the model. The model is fit via a Markov Chain Monte Carlo (MCMC) routine. MCMC produces a simulation of the plausible values of the posterior distribution given the data provided.

The MCMC routine ran through a user specified number of iterations and attempt to determine plausible values, or the proportion of each source in a sample, given the data input into the model. This information was then used to create the confidence intervals of the model sources. It is advisable to discard the first set of values determined in the MCMC as these may not represent a true convergence of the posterior distribution. This is referred to as “burn-in”.

The model was run for 500,000 iterations with the first 50,000 iterations discarded (burn-in). An uninformative prior distribution was specified in the models. The mixing model assumes the contribution of the sources add up to 100%. The means of all potential sources within the model will not necessarily add up to exactly 100% due to the different distributions for each source.
There are many potential sources of uncertainty with using mixing models with sediment data throughout a large catchment.

Differences in organic matter and particle size within samples can differentially affect the concentration of geochemical elements. A number of different correction factors have been used in the past to normalize concentration data between different samples. We have not used any correction factors because of the difficulty of applying a general correction factor across a number of different samples and elements (Pulley, Foster, & Antunes, 2015).

2.6 How to interpret model results?

The interpretation of the statistical results was based on the catchment conceptualization in order to track sedimentation from upstream to downstream with control of source location. Sources of sediment usually vary with time due to a number of reasons; therefore, the analysis was done at sub-catchment level on each individual set of samples as well as over the pool of samples (composite) across sampling campaigns (see Table 2 for more details). Results yielded the proportion of sediment arising from each geological type within that sub-catchment and are presented in graphical formats.

Box plots were utilized to show the modelling results for each individual suspended sediment sample and composite sample for all the campaigns. The box plot indicates the likely geological sources of sediments over the sampling period. These plots provide suspended sediment sources in the river at the time the sample was taken. The range of each sample in the box plot represents the 95% confidence intervals and the dot for each source represents the most likely value for that source (mean). The variation in the source of sediment per sample indicates changes in sediment sources over time in a sub-catchment, due to differences in rainfall and/or human activities. In addition, there is another plotted box plot which indicates the composite result. Note that the composite is not the average of all the sampling campaigns; it is obtained by pooling together the analytical results of all the samples across the sampling events.

Table 2: Summary of the number of samples and campaigns (timeslots) in Sebeya Catchment

<table>
<thead>
<tr>
<th>Catchment name</th>
<th># soil samples</th>
<th># sediment samples</th>
<th>Sampling campaign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sebeya</td>
<td>10</td>
<td>6</td>
<td>16 Oct-3 Nov 2017</td>
</tr>
<tr>
<td>Sebeya</td>
<td>11</td>
<td>14</td>
<td>14 Jan-26 Jan 2018</td>
</tr>
<tr>
<td>Sebeya</td>
<td>9</td>
<td>14</td>
<td>12 Feb – 22 Feb 2018</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30</strong></td>
<td><strong>34</strong></td>
<td></td>
</tr>
</tbody>
</table>

3. MODEL RESULTS

3.1 Geological contribution to sediment load in Sebeya Catchment

The mixing model of only the geological types within the entire Sebeya catchment found that the Ho geological type contributes the majority of the suspended sediments (Figure 7). The second highest amount of sediments were coming from either the Granites, Bu, B, or Nw geological types. The model found with high certainty that the Uw/Cr type does not contribute much suspended sediments to the outlet.
Figure 7: Mixing model source proportions for all geologic types in the Sebeya catchment. Dots represent the mean. Coloured boxes represent the 95% confidence intervals.

3.2 Sub-catchment contribution to sediment load in Sebeya Catchment

The mixing model using all the potential sub-catchments had more difficulty identifying the major sources of suspended sediment (Figure 8). However, the Nyangirimbiri and Karambo appear to be the larger sources of suspended sediments.
In the Bihongoro sub-catchment, Granites indifferenciés is the largest source of suspended sediments, followed by Bu (Figure 9). Ho is the smallest source of suspended sediments in this sub-catchment.
The most probable causes of the sediment sources distribution observed in this sub-catchment is likely related to: i) mining activities near its outlet in the granite indiferenciés formation (making it the highest contributor) and ii) Open land used for grazing largely (Figure 10) covering the Bu formation (without any erosion control measures).
Adding in the Nyanzo sub-catchment as a potential source within the analysis of the Bihongoro sub-catchment reveals that the Nyanzo is a major source of suspended sediments for the Bihongoro catchment (Figure 11). The model shows that Nyanzo contributes the most to sediment load into Bihongoro, probably from the Bu formation, likely because of grazing and mining activities (Figure 12). However, for all the sampling campaigns, Nyanzo River was found clean, since it also takes source from the grasslands and former Gishwati forest. These dense grasslands used for cattle grazing seem to protect the soil against erosion.
Figure 11: Mixing model source proportions for all geologic types in the Bihongoro catchment. Dots represent the mean. Colored boxes represent the 95% confidence intervals.

The confluence of Nyanzo (on the left) and Bihongoro (on the right)
3.2.2 Nyanzo

Nyanzo River is an affluent of Bihongoro River, crossing large areas of Rutsiro District before flowing into Sebeya. The Bu formation is largely covering the Nyanzo sub-catchment and seem to contribute the most to the sediment load into Nyanzo sub-catchment (Figure 13). Landscapes in Nyanzo are generally grasslands used for cattle grazing, but there are possibly some infrequent illegal mining along the river.
3.2.3 Pfunda

Pfunda River is one of the major tributaries of Sebeya, with 3 sub-catchments: Nyaburaro, Nyangirimbiri and Rwankuba. In the Pfunda catchment, all geologic sources appear to be equally important (Figure 14).

The confluence between Pfunda River (on the left) and Sebeya River (on the right)
When adding in the three sub-catchments (Nyaburaro, Nyangirimbiri and Rwankuba) into the analysis of the larger Pfunda catchment, the Nyaburaro catchment appears to be the largest sources of suspended sediments (Figure 15). Nyangirimbiri also drains landscapes with high erosion risk, but since few samples were collected in this sub-catchment, the model could not detect its major contribution to the sediment load into Pfunda River. Rwankuba River takes source from Gishwati forest, which is mainly a protected area, but some unsustainable mining and farming are likely to take place at some locations of this sub-catchment, making it also contributing to Pfunda’s sedimentation level. However, given that only one geological type covers Rwankuba sub-catchment, a separate analysis for this sub-catchment could not be done.

The Pfunda sub-catchment has mining, agriculture and grazing activities all over the sub-catchment (Figure 16). The contribution of granites indifferenciés in the Pfunda River, even though the formation is very small, but a concentration of mining sites is the cause the depicted contribution in the statistical results.
Figure 15: Mixing model source proportions for all geologic types and catchments in the Pfunda sub-catchment. Dots represent the mean. Colored boxes represent the 95% confidence intervals.
3.2.4 Nyangirimbiri

In the Nyangirimbiri sub-catchment, Bu is a larger source of suspended sediments (Figure 17). The main reason explaining the high sediment contribution of Bu formation in the Nyangirimbiri sub-catchment is likely due to mining activities near the river (Figure 18). In addition, poor irrigation or landslide near the outlet of the river. For the Ho formation, maybe the small contribution of sediment depicted in the statistical results could make the formation to be among the most contributors, since the corresponding land uses do not pose much problem.
Figure 17: Mixing model source proportions for all geologic types in the Nyangirimbiri sub-catchment. Dots represent the mean. Coloured boxes represent the 95% confidence intervals.

During heavy rainfall, Nyangirimbiri water increases and carries much soil materials into Pfunda River.
Figure 18: Nyangirimbiri sub-catchment

Mining in Kavomo cell, covering Nyangirimbiri sub-catchment
3.2.5 Nyaburaro

In the Nyaburaro sub-catchment, Bu appears to be a marginally larger source of suspended sediments (Figure 19).

Mining activities in the Nyaburaho sub-catchment, within the Bu formation, is the most probable cause of high sediment contribution in the river (Figure 20). In addition, the limited contribution of Ho formation, located at the outlet of the catchment, indicates poor agriculture activity or landslide.
A landslide was observed (during field validation – October 2018) in Kavomo Cell, Nyundo Sector, covering Nyaburaro sub-catchment.
### 3.2.6 Karambo

In the Karambo sub-catchment, the model found that B and Ho formations are the larger sources of suspended sediments (Figure 21). In Karambo, agriculture and mining activities are the major land use (Figure 22). The contribution of the geological formation B is likely related to mining activity near the river course. However, the contribution of Ho is most probably related to landslide that occurred prior to sampling (the rational of this is the size of the formation and its location to the outlet of the sub-catchment).

*Figure 21: Mixing model source proportions for all geologic types in the Karambo sub-catchment. Dots represent the mean. Coloured boxes represent the 95% confidence intervals*
Figure 22: Karambo sub-catchment

The confluence between Karambo and Sebeya River in Kanama Sector, Rubavu District
When adding the Yungwe sub-catchment as a potential source within the larger Karambo sub-catchment, the Yungwe does not appear to be a major source of suspended sediments except potentially during episodic events (see Karambo-3, Figure 23). The grasslands and planted forests in Nyabihu (Figure 25) are likely to have a very low erosion risk.

Figure 23: Mixing model source proportions for all geologic types and catchments in the Karambo sub-catchment. Dots represent the mean. Coloured boxes represent the 95% confidence intervals.

Yungwe River crossing rocky landscapes in Kanama Sector, Rubavu District.
3.2.7 Yungwe

In the Yungwe sub-catchment, Granites indifferenciés is the largest source of suspended sediments (Figure 24).

![Graph showing mixing model source proportions for all geologic types in the Yungwe sub-catchment. Dots represent the mean. Coloured boxes represent the 95% confidence intervals.]

*Figure 24: Mixing model source proportions for all geologic types in the Yungwe sub-catchment. Dots represent the mean. Coloured boxes represent the 95% confidence intervals.*
3.2.8 Bikeneko

The mixing model had difficult separating the sources within the Bikeneko. However, Bu did appear to be a slightly larger source of suspended sediments (Figure 26).
The situation in Bikeneko sub-catchment is related to the fact that grazing is practiced mostly in the catchment largely covered by the Bu formation (Figure 27). Grazing on the created rangelands/pasturelands does not seem to contribute to soil erosion, but mining is done at some locations inside rangelands. Also, In Bugarura Sector, some rangelands are abandoned and farmers start practising agriculture without erosion control measures. However, for better depiction, more sediment sampling is necessary.
3.2.9 Bitenga

In the Bitenga sub-catchment, Ho was the largest source of suspended sediments, followed by Bu (Figure 28).
Figure 28: Mixing model source proportions for all geologic types in the Bitenga sub-catchment. Dots represent the mean. Coloured boxes represent the 95% confidence intervals.

The confluence between Bitenga River (on the left) and Sebeya River (on the right) in Rutsiro District.
The situation in Bitenga sub-catchment is related to agricultural activities. Irrigation is heavily practiced in the floodplain of the river on top of the Ho formation. The high contribution of sediment from this source may indicate a poor irrigation practice in the area causing a loss of soil. In addition, the catchment is largely covered with the Bu formation on top of which extensive agriculture is practised (Figure 29). The sediment contribution from this formation may indicate poor agricultural practices in the area.

Figure 29: Bitenga sub-catchment
Agriculture on abandoned rangelands/pasturelands, and without any erosion control measures: Murunda Sector, Rutsiro District

3.2.10 Gatare

In the Gatare sub-catchment, Bu is the larger source of suspended sediments (Figure 30). In the Gatare sub-catchment, a combination of agriculture, grazing and mining activities in a largely Bu formation explains the statistical results (Figure 31).
Sediment fingerprinting in Sebeya Catchment, north western Rwanda

**Figure 30:** Mixing model source proportions for all geologic types in the Gatare sub-catchment. Dots represent the mean. Coloured boxes represent the 95% confidence intervals.

The confluence between Gatare and Sebeya River. Gatare seem to stay clean when there is no heavy rainfall, this also supporting that its sedimentation is mainly caused by agriculture without erosion control.
In the Kagera catchment, Bu is the larger source of suspended sediments (Figure 32). Agricultural activities in the Kagera sub-catchment are likely the primary cause of erosion. It is clear however, from the statistical results and geological formation in this catchment that, Ho is not heavily contributing to sedimentation potentially due to a well-designed and constructed irrigation scheme in the Kagera floodplain (Figure 33).
Figure 32: Mixing model source proportions for all geologic types in the Kagera sub-catchment. Dots represent the mean. Coloured boxes represent the 95% confidence intervals.
When sediment were trapped from Kagera River, it was clean the first time (during light rain), and plenty of sediment the second campaign during months of heavy rain.

The confluence between Kagera and Sebeya River. Kagera was observed clean (photo on the left – during a slight rain of October 2017), but the sediment load was high during medium rainy season of January 2018.

Figure 33: Kagera sub-catchment
4. PRIORITIZATION OF AREAS HEAVILY AFFECTED BY EROSION

This step uses the results from the mixing model, to produce an erosion hotspot map, which shows areas with priority climate change interventions.

4.1 Description of the prioritization process

The prioritization process starts from upstream sub-catchments to downstream. This allows looking at the sediment sources right at the very beginnings of the river drainage. The initial prioritization was as follows:

- Level 1: geological types that contributed 40% or more sediment.
- Level 2: 20-40%
- Level 3: 10-20%

Geological types contributing less than 10% were not assigned any priority level (i.e. negligible). Now, as a river flows and joins other tributaries downstream, each tributary comes in with its own sediment load. Furthermore, as a river flows, some sediment settles out in slow flowing zones, such as river bends, wetlands or flow obstructions, while new sediment comes in. Hence, the sediment composition changes with space and time as one goes downstream. It is possible that a sediment source that may have been a major contributor in an upstream catchment is no longer as dominant downstream. To account for this dynamic change in sediment composition as one goes downstream, a further prioritization strategy is taken as follows:

**Level 1**: assigned to a geological type that retains its dominance in sediment contribution downstream, as seen from the sediment composition results at a downstream point on the river.

**Level 2**: geological types that were Level 1 in an upstream catchment but decrease in contribution level downstream.

**Level 3**: geological types that were Level 2 in an upstream catchment and decrease to Level 3 or less.

This process is repeated for results from each downstream sampling point, until the requisite region is covered. It is important to note that areas other than identified as levels 1-3 also do contribute sediment, because of the loss/reduction of forest cover for example. However, areas under levels 1-3 contribute anywhere between 50% and above of the total sediment. Such maps greatly help focus limited resources on rehabilitating areas with the highest levels of soil erosion and sediment generation.

4.2 Potential erosion hotspots map

The map is the final result of the sediment fingerprinting. It shows sites with high and less contribution to erosion in Sebeya Catchment (Figure 34). Since this map contains a spatial information, a ground truth was important to see exactly the match and mismatch between the model outputs and the reality on the ground.
Figure 34: Map showing potential erosion hotspots in Sebeya Catchment
The ground truth was approximately 90% matching with the modelling results (Annex 2; Figure 35). Differences can be attributed to the few sampling campaigns (only three) for sediments, and the soil samples were not collected at all mining sites, all forest and agriculture, so to allow a comparison between different land uses.

Huge active mining in Bugarura Cell, Ngororero District. This mining site is owned by an individual investor, and it has been operating since 1990 by former mining companies in Rwanda (e.g. SOMUKI).

Generally non-sustainable mining and agriculture were found exactly in the category of “level 1”, while natural forest (i.e. Gishwati), tea plantations, planted forest, slopes with agroforestry were found to contribute to less than 10% to Sebeya River sedimentation. This category also includes landscapes with lava soils, some non-degraded rangelands/pasturelands used for cattle grazing and sites with sugar cane plantations.

Such lava soils were mainly found in level 3 or same category as natural forest (i.e. less than 10% contribution to sediment load in Sebeya Catchment)
Representatives of local communities (SSGs) participated in the activities for sediment fingerprinting ground truth: one community group based in Rubavu and one from Rutsiro District. Approximately 30 members in total were engaged with this fieldwork, and could propose some possible erosion control measures, which are not far from the already existing practices for land rehabilitation in Rwanda.

Field verification with the community engagement for suggesting land protection actions

### 4.3 Erosion hotspots by sub-catchment and district

The erosion hotspot map was reclassified, to give a level 0 to the landscapes contributing to less than 10% to the river sedimentation. The map was also converted into a shapefile, to allow calculations on erosion hotspots coverage by district (Table 3). The differences in percentage contribution to erosion in Sebeya Catchment can also be compared with elevation range. It is clear that Rubavu district with the lower elevation falls under sites with less erosion contribution (Figure 36). This is to mean that Rubavu might be affected by flooding and erosion, coming from the higher elevation landscapes of Ngororero, Rutsiro and Nyabihu.

#### Table 3: The areas (in km$^2$) covered by different erosion hotspots per district

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<th>Area level 0 (km$^2$)</th>
<th>Area level 1 (km$^2$)</th>
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Figure 35: Reclassified hotspot map, and showing sites visited during field verification. Note that Gishwati National Park (shared between Rutshiro and Ngororero Districts) is one of the areas with less contribution (below 10%) to erosion in Sebeya Catchment.
Figure 36: Comparing the erosion hotspots per district and at different elevation ranges in Sebeya Catchment
5. PROPOSING EROSION CONTROL MEASURES IN SEBEYA CATCHMENT

This step will build on the sediment fingerprinting results, but at the same time consider ongoing land rehabilitation initiatives and community involvement. Climate change vulnerability assessments will be carried out with communities from selected sites (especially category “level 1”), to complement the sediment fingerprinting study. Furthermore, the suggested erosion control measures by the Ministry of Environment (MoE, 2018) will guide the on-the-ground interventions.

Looking at the size of areas with higher contribution to erosion, BirdLife cannot put in place interventions at once and covering all these places. But, based on the modelling results showing the contribution of each sub-catchment to erosion in Sebeya Catchment (Figure 8), the selection of areas for interventions can be narrowed. The targeted unit is a sub-catchment which covers a certain district, sector, cell and village (Figure 37). The final list (Annex 3) of sites to plan for interventions also excluded areas with ongoing and planned initiatives by the Water for Growth Rwanda: these are part of Karambo, Bihongoro and Gat are sub-catchments.
Figure 37: Erosion hotspots per sub-catchments in Sebeya Catchment. Areas not delineated into sub-catchments are part of the Sebeya corridor.
6. CONCLUSION

This study using sediment fingerprinting, was conducted to identifying different levels of erosion hotspots: areas with high, middle, low and very low contribution erosion, which in turn cause river sedimentation in Sebeya Catchment of Rwanda. The research was designed based on land use/land cover categories, geological types, soils, drainage systems and topography. The sediment fingerprinting as a scientific tool was selected, because it has not yet been applied in many places of Rwanda (this is the second similar study), and it is a potential technique which can guide the on-the-ground interventions to control erosion and hence sedimentation in a catchment. Sebeya River in the north western Rwanda was targeted, because it is part of the large Kivu-Rusizi basins, which have been of interests for BirdLife International, to implement the climate change resilience interventions for local communities. This initiative is known as CRAG: “Climate Resilient Altitudinal Gradients” and it is funded by the MacArthur Foundation, since April 2014 till December 2019. In addition, Sebeya provides a number of ecosystem services, which could be diminished if there is no continuous catchment management practices in place.

The soil samples were collected once, while sediments were trapped three times. Basically, the mixing model requires at least 5 sampling campaigns to be able to make very accurate predictions. But, the analysis is still possible when sediment sampling is repeated only three times, and results were interesting, and comparable to similar studies on erosion risk in Rwanda, and confirmed by a fieldwork for ground truth.
These findings show that there are sites in Sebeya with unsustainable land uses, which need some interventions, after consultation and mobilisation of local communities.

Farming on steep slopes without erosion control, mining on the hills and along Sebeya River bank highly contribute to the river sedimentation. It was also interesting to find that protected landscapes were categorized by the analysis as areas with less to no contribution to the sediment load into Sebeya River. These comprised of a Key Biodiversity Area (Gishwati National Park), non-degraded rangelands/pasturelands, areas with planted forest (especially Alnus species), and sites with lava soils.

The sediment fingerprinting requires time and skilled project team, especially for the study design using GIS, knowledge of water resources in the targeted catchment, and statistical analysis with R. The results from this research are very useful to guide on interventions for climate change resilience for local communities in Sebeya Catchment.

REFERENCES


ANNEXES

Annex 1: Sample test results from the Rwanda Standards Board and 42 elements analysed for each sample submitted

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Annex 2: Field data verification of erosion hotspots areas
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### Annex 3: Narrowed list of sub-catchments and their administrative boundaries – targeted for interventions by BirdLife

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BirdLife International
Partnership for **nature** and **people**

www.birdlife.org

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BirdLife International is the world’s largest nature conservation partnership. Through our unique local-to-global approach, we deliver high impact and long term conservation for the benefit of nature and people.

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