Journal of Water Resource and Protection, 2015, 7, 1387-1398
Published Online November 2015 in SciRes. http://www.scirp.org/journal/jwarp
http://dx.doi.org/10.4236/jwarp.2015.716112

Performance Evaluation of Sediment Basins: Case Study of Keya Hydropower Plant in Rwanda

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Received 24 September 2015; accepted 24 November 2015; published 27 November 2015

Abstract

Keya Hydropower Plant (HPP) is a run-off-river plant which can be an effective green solution contributing to the current energy demand in Rwanda but a huge amount of sediment contained in water of Sebeya River on which this plant is built results in loss of the plant capacity. The aim of this study was to conduct the performance evaluation of Keya HPP sediment basin located in Rubavu district, western province of Rwanda. Specifically, laboratory tests of sediment, efficiency of the basin, assessment of sedimentation problems on HPP operations, proposition of technical options for increasing the removal efficiency of sediment basin and other options for reducing sediment at the source of generation were performed using different methods including interviews and questioning Keya hydropower technicians, field sediment sampling followed by hydrometer and Particle Size Distribution (PSD) analysis. Analysis was made in University of Rwanda (UR) Soil Mechanics laboratory. MICROSOFT EXCEL and Graphisoft Archicad 18 softwares with Massachusetts Institute of Technology (MIT) soil classification were used as data analysis tools. Results showed that the overall efficiency removal of the diversion headwork was 85%. However, after comparing sediment concentration at the inlet and outlet of the sediment basin, it was found that the basin removed only 22% of sediment from diverted water toward the turbine. This means that 78% of sediment escapes the basin to cause erosion on the turbine components resulting in reduction of the plant capacity from 2.2 MW to 900 KW. To ensure sustainable solution to sediment issues in Keya HPP, an upstream sediment trap reservoir is proposed. It is recommended also that Rwanda Energy Group (REG) should work together with Rwanda Natural Resource Authority (RNRA) at national level to ensure sustainable development of erosion control in the Sebeya catchment area.

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How to cite this paper: Munyaneza, O., Majoro, F., Mutake, S. and Hagenimana, E. (2015) Performance Evaluation of Sediment Basins: Case Study of Keya Hydropower Plant in Rwanda. *Journal of Water Resource and Protection*, **7**, 1387-1398.
http://dx.doi.org/10.4236/jwarp.2015.716112

Keywords

Keya Hydropower Plant, Sediment Basin Evaluation, Sebeya River, Rwanda

1. Introduction

For most of power plants in rivers with sediment problem, there must be sediment basin systems. Generally, a sediment basin is built for trapping suspended sediment particles before they reach the turbine components. The performance of this basin depends on its ability to trap suspended sediment and its ability to remove the trapped deposits from the basin. Even if it is not possible to trap all suspended sediment, efforts should be made in removal of most of sand fractions before flowing to power house to reduce the sediment load on turbine and efficiency loss and obtain the required power generation [1].

Keya HPP is a runoff river project established in July 2011, in Nyundo Sector, Rubavu District of Western Province of Rwanda with a capacity of 2.2 MW and draws its water from Sebeya River and the hydropower plant is now facing with different issues of sedimentation.

Run-off-river projects are HPP constructed to utilize the available water throughout the year without having any storage. These projects usually consist of a small diversion weir or dam across a river to divert the river flow into the water conveyance system for power production (**Figure 1**). Therefore, these projects do not have dam reservoirs to retain sediment but should be able to bypass the incoming bed load to the river downstream. The suspended sediment will follow the diverted water to the conveyance system. Settling basins are constructed close to the intake to trap certain fractions of the suspended sediment [2].

Sediments are fragments of rocks and minerals, loosened from the surface of the earth due to weathering processes and the impact of rain, blowing winds and flowing water. Sebeya River is taking its origin in high elevated mountains of Gishwati forest in the south of Rubavu District, western province of Rwanda. An important challenge faced by Keya HPP developed on this river is the difficulty of operation and maintenance of the plant due to large quantity of sediment inflow with hard and abrasive minerals [3].

The inlet part at which the penstock is connected to its called forebay tank is basically a pool located at the end of sediment basin from which the penstock pipe draws the water. The forebay tank serves the purpose of providing steady and continuous flow into the turbine through the penstocks. The forebay also acts as the last settling basin and allows the last particles to settle down before entering the penstock. The forebay size depends on the length

Figure 1. Sediment basin, forebay tank, and trash rack and sediment effects on turbines.

of the penstock pipe. The longer the penstock pipe is, the bigger the forebay and the sediment basin will be [4]. A trash rack is mounted at the inlet of forebay tank to prevent floating debris from getting into the penstock. There are different types of trash racks either thinly spaced vertical steel bars or rods or a plate with holes or slots [5]. The trash rack should be built strong enough to withstand the water pressure. To allow simple maintenance during operation, the bars in any trash rack should be sufficiently spaced. If the space among the individual bars is too small, the gross head will drop down and the energy output will decrease.

2. Study Area

Keya micro hydropower is located in Nyundo sector, Rubavu district of western province in the vicinity of Pfunda tea factory on the left side of the main road toward Gisenyi town and upside of the road warding Kibuye (**Figure 2**). Rubavu district is bordered at East by Nyabihu district, West and North by Republic Democratic of Congo and south by Rutsiro district. Keya micro hydropower plant is located next to the watershed of Crete Congo-Nile across Sebeya River. The Crete Congo-Nile characterized by rushed erosion which is clearing hills and expanding new vulnerabilities in different valleys, flows of rivers, plains and lakes. **Figure 2** shows Keya micro hydropower plant location.

Infrastructures of this plant include intake structures, sediment basin, forebay tank, power house and administration office at the hydropower plant. The sediment basin of this plant is located in 1125 m from the power house with gross head equals to 91.99 m. The total head loss was found to be 4.51 m, so the net head measured from tailrace level is equal to 87.58 m [3].

The turbine used at the site was OSSBERGER cross flow turbine. Cross flow turbine is a radial and partial admission free stream turbine. It is classified as slow speed turbine with horizontal runner and horizontal shaft. In a cross flow turbine, water passes through the turbine transversely, or across the turbine blades which ensures self-cleaning of the rotor and protect the turbine from clogging [6].

3. Data and Methods

3.1. Site Visit

In this study, the site visits were done to Keya HPP frequently in order to get more information about the current behavior of sediment basin during rainy and dry periods and sediment related issues in hydropower plant.

Sediment samples were collected at both inlet and outlet of the basin as shown in **Figure 3**.

3.2. Survey Methods

Questionnaire and interviews were conducted at the site. The interviewees were addressed to both site engineers and neighborhoods with agriculture practices in the hill side surrounding Sebeya River and with quarry of sand deposits in the river banks. Questionnaires were addressed to both Keya HPP site technicians and the neighboring people and set on sediment issues in hydropower plant and environment and sediment removal techniques.

The questions of interview included: (1) What are the sources of sediment deemed to be significant faced by Keya HPP? (2) During which periods of the year Keya HPP experiences issues related to sediment? (3)What are sediment issues to Keya HPP? (4) What is sediment removal techniques used at the site? And (5) Are there environmental problems associated with being nearby the plant?

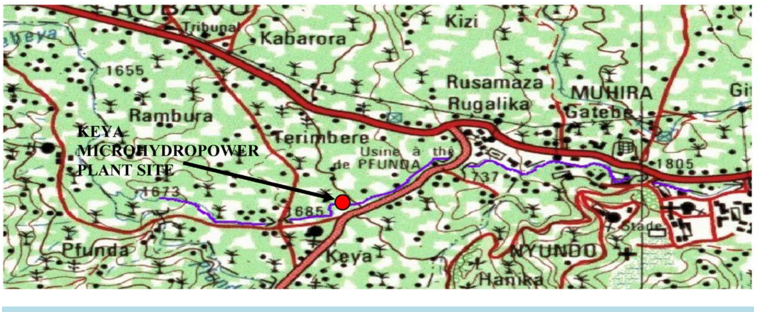

Figure 2. Keya micro hydropower location (Envirotech, 2014).

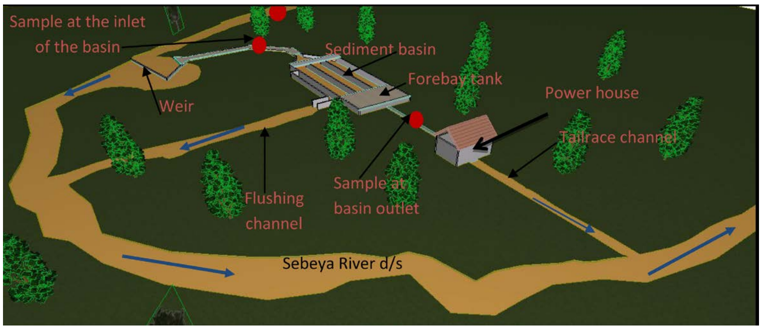

Figure 3. Physical representation of the site with sampling points.

3.3. Sieve Analysis Test

Particle size of sediment is one of the promising factors in which erosion potential of sediment depends. All size range of sediment particles do not reaches turbine.

3.4. Determination of Sediment Concentration

The concentrations of sediment at the inlet and outlet of the basin were determined using displacement method to determine the removal. Displacement method consists of the determination of the difference in weight between a sample of sediment laden water and an equal volume of clean water [7].

Procedures

1) Measuring sediment concentration C_{in} at the inlet of sedimentation basin using Equation (1).

$$C_{in} = K\left(W_{si} - W_{w}\right) \quad (1)$$

where:

C_{in}: Sediment concentration at the inlet of sedimentation basin;
W_{si}: Weight of sediment laden water at the inlet of the basin;
W_{w}: Weight of clear water;
K: Coefficient = $\rho s\left(\rho - \rho s\right)W_{w}$ with ρs as density of sediment.

2) Measuring sediments concentration C_{out} at the outlet of the settling basin by using Equation (2).

$$C_{out} = K\left(W_{so} - W_{w}\right) \quad (2)$$

where:

C_{out}: Sediments concentration at the outlet of the settling basin;
W_{so}: Weight of sediment laden water at the outlet of the basin.

Then, the efficiency of sediment basin (η) is obtained as follow:

$$\eta = \frac{\left(C_{in} - C_{out}\right)}{C_{in}} \times 100 \quad (3)$$

This removal efficiency of the sediment basin is equivalent to the difference between the percentage passing at the inlet minus the percentage passing at the outlet of the basin obtained [7]. In this study, the removal efficiency of sediment by sediment basin from water that reaches the turbine was evaluated by comparing sediment samples collected at the inlet to those collected at the outlet of the basin by means of sieve analysis.

3.5. Data Analysis Tools

Microsoft (MS) excel was used for data analysis and helped in getting different sieve and hydrometer analysis grading curves from which percentage of sediment removal by the basin was estimated. Massachusetts Institute of Technology (MIT) soil classification was used to analyze type and size of sediment. Graphisoft archicad 18 was used to draw top view of the proposed upstream reservoir with the representation of the site which shows Keya hydropower plant locations where sediment samples were taken.

4. Results and Discussion

4.1. Sources of Sediment in Sebeya River

Using interview and field visits, we found that rainfall-driven erosion process enhanced by deforestation and cultivation practices presently adopted on sloping lands appears to be the primary cause of soil erosion in the catchment areas of Keya HPP. Deforestation and cultivation practices make the soil loose so that it is easily removed by the rainwater. This can be gradually developed into water flow in small channels, known as rills and gullies, which are developed continuously and cumulatively soil particles are detached from each other into River. We also found that quarrying minerals and sand along river banks contribute to sediment loading in Sebeya River leading to severe sedimentation and the river color constantly deep brown. This is counterproductive to the amount and quality of water available for hydro power generation by the plant.

4.2. Questionnaire Design Results

The results from the analysis of questionnaires have provided an overview of sediment issues faced by the plant. It was found that sediment issues become worse during rainy period due to excessive amount of sediment carried in river due to runoff and becomes difficult for the sediment basin to remove sediment before they reach the turbine. The settled sediments are removed from the basin by using hydraulic technique (flushing) and mechanical removal (dredging) and discharged back into the river as shown in **Figure 3**. Sediments damaging the turbine lead to the reduction of the plant capacity from 2.2 MW to 900 KW as well as working hours from 24 hours to 5 hours per day as reported by Keya HPP Technician called Ndererimana Vincent. Sediments damages result also to the necessity of frequent replacement of damaged turbines.

4.3. Sediments Concentration at Inlet and Outlet of the Sediment Basin

The concentrations of sediment at the inlet and outlet of the sediment basin were determined using displacement method described in Equation (1), (2) and (3) as and the calculation procedures are as follows:

Knowing that, the density of sediment ρs in Sebeya River was found to be 1260 kg/m^3, density of clean water ρ is 1000 kg/m^3 and the weight W_w of 1 L of clean water is 1 Kg, the coefficient $K = \rho s(\rho - \rho s)W_w$ is computed and found to be **0.3276**.

For the weight of 1 L of water laden sediment W_{si} at the inlet of the basin was found to be 1560 g/L, which means that the sediment concentration at the inlet of the sediment basin using Equation (1) is equal to **183.456 g/L**.

Again for the weight of 1L of water laden sediment W_{so} at the outlet of the basin was found to be 1436.782 g/L, which means that the sediment concentration at the outlet of the sediment basin using Equation (2) is equal to **143.09 g/L**. However, the efficiency of sediment basin (η) is obtained from Equation (3) and is found to be 22%.

This means that about 78% of possibility for sediment escape sediment basin.

4.4. Particle Size Distribution and Hydrometer Test Results

Sieve analysis and hydrometer test results were plotted in a semi-logarithm graph called sieve analysis grading curves as shown in **Figures 4-6**. In these figures, particle diameters were plotted in log-scale and corresponding percentage finer in arithmetic scale. Main advantage of using semi-logarithm graph is that it can bring out features in the data that would not easily be seen if both variables have been plotted linearly.

The tables of results for sieve analysis and hydrometer tests at each sampling site are shown in the Appendices 1 to 4 while **Table 1** shows the Massachusetts Institute of Technology (MIT) soil classification used to analyze the type and size of sediments.

4.4.1. The Effects of Headwork on Sediment Removal from the Diverted Sebeya River

The effect of headwork (weir at the intake) on sediment removal from the diverted Sebeya River was performed by making comparison between sieve analyses graphs of sediment samples collected at upstream of the intake and that collected at the inlet of sediment basin (**Figure 4**). The significance of those curves is their slopes which show the size in which most of the particles are ranging. At the upstream of the intake, the percentage finer curve has steep gradient in the size opening ranging from 0.212 mm to 0.6 mm which indicates that about 74% of the sediment was in that range while at the outlet of the intake, most of the sediment ranges between 0.212 mm and 0.425

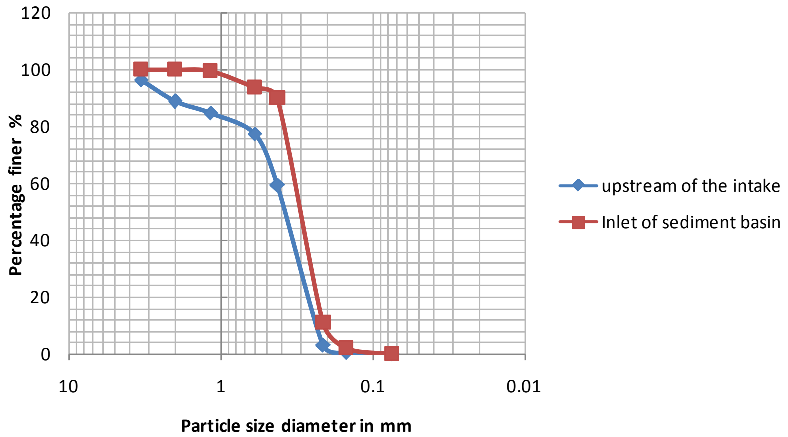

Figure 4. Grading curves at inlet and outlet of the headwork.

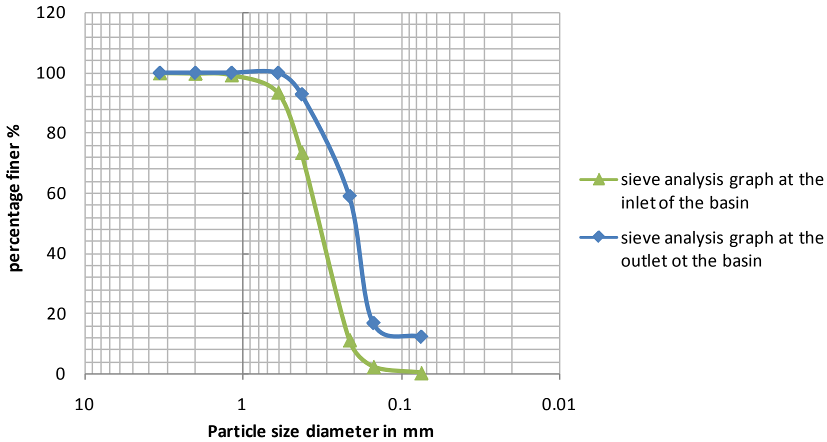

Figure 5. Inlet and outlet grading curves for sediment basin.

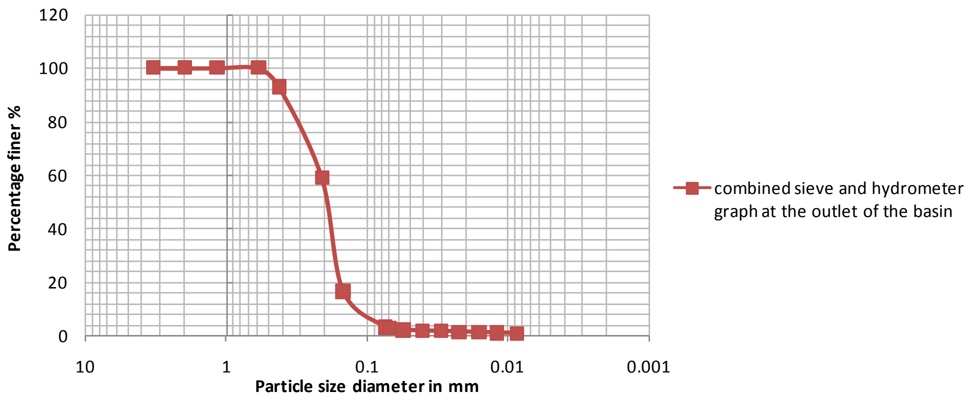

Figure 6. Typical grading curve at the outlet of the sediment basin.

Table 1. MIT soil classification used to analyze the type and size of sediment [8].

Gravel	Sand			Silt			Clay
	Coarse	Medium	Fine	Coarse	Medium	Fine	
2	0.6	0.2	0.06	0.02	0.006	0.002	(mm)

mm with 78.67% of the total intake sediment. This means that the percentage finer increases from inlet to outlet because most of settled sediments are dominated by coarse sand and gravel.

Figure 4 shows that quantitatively from the grading curves; **Table 2** depicts the type and the percentages of sediments removed by the headwork.

Table 2 shows that by comparing the proportions of sediment at the upstream of intake and that at the inlet of sediment basin, we found that 33% of total sediment reaching the weir including 11.13 % of gravel, 5.25% of coarse sand, 8.85% of medium sand and 7.85% of fine sand are removed. This means that 67% of sediment composed mainly with a mixture of medium sand, fine silt containing sand and clay while non-settled gravels and vegetal debris are removed by a series of trash racks fixed at the inlet of sediment basin (see **Table 1**). These results are in line with results obtained by Rwanda Natural Resources Authority (RNRA) which showed that Sebeya catchment is composed of clay soil composed with micaschists fragment gravels, dry silty fine sand alluvial material with mica particles, quartz and grass rootlets [9].

4.4.2. Removal Efficiency of Keya HPP Sediment Basin

At the inlet of the basin, gradient curve is steeper between the sieve openings ranging from 0.15 mm to 0.425 mm which means that about 85.5% of sediment falls in that range, 10.25% ranges from 0.425 mm to 3.35 mm and 4.25% between 0.15 mm to 0.075 mm (**Figure 5**). Great amount of sediment that reaches the outlet of the basin range between 0.15 mm and 0.212 mm with 42.23% of the total amount of sediment that escape from the basin without being settled. From the remaining 2 portions of this outlet grading curve, 4.58% ranges between 0.075 mm to 0.15 mm and 40.97% range from 0.212 mm to 3.35 mm.

Figure 5 shows that quantitatively from the grading curves; **Table 3** indicates the type and the percentages of sediments removed by the sediment basin.

Table 3 shows that river sediments flowing along with water passing through the turbine are the reasons why the sediment erosion in hydraulic turbine components occurs. The river sediments are in the form of clay, silt, sand and gravel [10].

After all these percentages of particle removed, it was found that sediment basin removes fine and medium sand with silt and clay at the proportion of 21.68% say 22% of the total sediment that enters the basin.

This means that about 78% of possibility for sediment including fine and medium sand, silt containing quartz and clay escape sediment basin and flow through the penstock to erode turbine components.

Table 2. Indicative percentages of sediment removed by the headwork.

Type of sediment		Sediment size (mm)	% of upstream sediment	% of inlet sediment	% of sediment removed by the headwork
gravel		above 2	11.346	0.212	11.134
sand	coarse	0.6 - 2	11.466	6.222	5.246
	medium	0.2 - 0.6	73.859	82.379	8.85
	fine	0.06 - 0.2	3.329	11.183	7.854
The total percentage of sediment removed by the head work: 33%					

Table 3. Indicative percentages of sediment removed by the sediment basin.

Type of sediment		Sediment size (mm)	% finer of the sediment at outlet of basin	% of inlet sediment	% of sediment removed by the sediment basin
gravel		Above 2 mm	0	0.166	**0.166**
sand	**coarse**	2 - 0.6	0	6.266	**6.266**
	medium	0.6 - 0.2	77.97	82.522	**4.552**
	fine	0.2 - 0.06	21.698	11	**10.698**
Total percentage of sediment removed by the basin: 21.676 say 22%					

4.4.3. The Effects of Sediment on the Operation of Keya Hydropower Plant

From the results obtained in Section 4.4.2, we found that the efficiency of sediment removal by sediment basin is only about 22%. This means that about 78% of particles including fine sand, silt containing quartz and clay escaping the sediment basin without settled. **Figure 6** shows a typical grading curve at the outlet of the sediment basin. Thus, sediment became a major technical challenge to the smooth operation of Keya HPP because sediment hampers the efficiency and productivity of this plant (see **Figure 7**).

Keya HPP started its operation in July 2011 but due to this sediment issues; the turbine was damaged after only six months of operation (**Figure 7**).

From October 2012 to December 2013, the plant was out of use waiting for a new turbine to replace the first damaged one. After installation of the second turbine, the new turbine was also damaged in May 2015. From May 2015 up to now, the plant capacity of 2.2 MW was reduced to 900 KW and the working hours were reduced from 24 hours to 5 hours per day from 17h00 to 22h00.

The abrasive wear involves processes such as micro cutting, fatigue, grain detachment and brittle fracture. The erosion of turbine is highly depend on the size of the sediment particles, particle sizes above 0.2 to 0.25 mm (fine and medium sand) are more harmful. In 2010, Neopane [10] found that large size sediment particles above 0.25 mm (medium sand) even with hardness lesser than 5 on Moh's scale cause wear. Abrasive wear is the loss of material by the passage of hard particles over a surface. This wear occurs whenever a solid object is loaded against particles of a material that have equal or greater hardness.

Similarly silt with size less than 0.05 to 0.1 mm; containing quartz wears out the underwater parts. Fine sediment are more dangerous if the turbine is operating under high head [10].

4.5. Alternative Options to Increase the Performance of Keya HPP Sediment Basin

4.5.1. Provision of an Upstream Reservoir

If an upstream reservoir is provided before the river water enters the intake of sediment basin (**Figure 8**), the flow of sediment will be reduced as a high quantity will be settled at the bottom of reservoir before water reaches sediment basin resulting in removal of sediment. The measures against reservoir sedimentation can be divided in three groups, which are deposition control, removal of deposited sediments and compensation of reservoir silting [11].

4.5.2. Deepening and Widening Reservoir Formed by the Weir

We have observed that weir, river and intake share the same level resulting to direct diversion of sediment in the

Figure 7. Turbine damaged 6 months only after its operation.

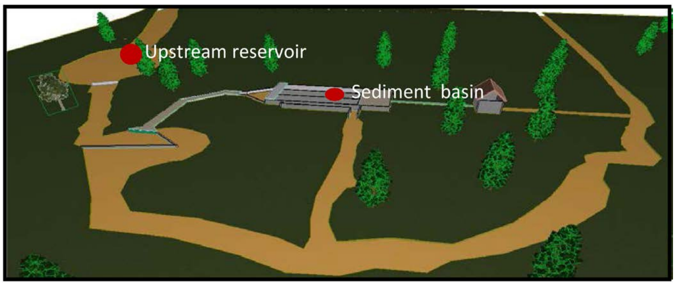

Figure 8. Top elevation of HPP site showing measures to increase sediment performance.

basin because there is no height to which sediment can settle provided bellow the intake level during construction of headwork. This is also cause of failure of sediment basin since most of sediment from river enters the intake without being diverted. Thus, we recommend deepening and widening the weir area so that the level of the intake is kept at high elevation than the river bed to ensure sufficient settling height.

4.5.3. Provision of Headrace Channel

In most of HPP constructed on sediment-laden river are provided with headrace channel of at least one kilometer with gentle slope to ensure settling of coarse particles before entering sediment basin and reduce its performance removal by over burdening it [12]. Thus, this channel can also be a good solution of sedimentation in Keya HPP after finding out whether the topographical condition of the site is feasible for this channel.

5. Concluding Remarks

On the basis of the experimental analysis, the size of sediment particles is not equally distributed in different locations of Keya HPP. Bigger particle size was found in the head works and it was observed that particle size decreased while the sediment particle traveled from the head works to tailrace. Headwork and sediment basins were found to remove only 33% and 22% of total sediment, respectively. This percentage shows poor performance of sediment basin at Keya HPP as a whole because about 78% of quartz sediment that escapes the basin without being settled causes serious damage of the turbine (OSSBERGER cross flow turbine) components (**Figure 7**). As described in Section 4.4.3, this turbine damage results in loss of the plant efficiency and causes power reduction in the national grid in addition to an increase in operational and maintenance cost due to periodic replacement of damaged turbines (**Appendix 5**).

So, we recommend providing an upstream reservoir for trapping a given quantity of sediment so that the constructed sediment basin removes the remaining sediment before water power enters the penstock to the turbine or redesigns Keya hydropower head works which include the redesign of Keya sediment basin.

We conclude by recommending Rwanda Energy Group (REG) to work together with Rwanda Natural Resources Authority (RNRA) and national government to ensure sustainable development of erosion control in the catchment area which acts as the main source of sediment in Sebeya River by implementing upstream control strategies of reducing sediment inflow in Sebeya River such as sediment control using terracing method which can reduce sediment yield by over 50% [13], revegetation of the surrounding area for the Stabilization of the steep slopes [9] as well as engineering measures like bench and trenches which can be adopted to stabilize soil and water on the hills.

These measures can be complemented by vegetative measures like afforestation, shrub planting, grass planting and agroforestry tree species. Stabilization of the river bank and its tributaries by planting bamboo at the river banks can be also recommended. In that way, bamboo nursery should be prepared at each cell in the watershed by farmers during community work. Thereafter, bamboo will be planted along Sebeya and its tributaries from upstream to downstream part for development of public participation in the catchment and river bank management plan.

Generally, sediment is a problem for the development of hydropower plants. Sediment management is important for longer life of turbine components. A common knowledge or general awareness of sediment problems is not enough to tackle this issue. Hydro power engineers must be "*sediment conscious*" during investigations, design, operation and maintenance, and even upgrading and refurbishment. More research and development is needed into the causes and mitigation of sediment erosion impacts. Experiments and field observations are needed to understand the true relationship among the sediment characteristics, wear resistance of base material, relative velocity of water, angle of attack of sediment particles, and chemical properties of water. More engineers should be trained in sediment engineering in order to raise a proper consciousness of the importance of sediment problems in the benefit of better planning, design and operation of run-of-river plants.

Acknowledgements

The work reported here was undertaken as part of a project carried out by the University of Rwanda (UR), School of Engineering. The authors wish to acknowledge the support of Government of Rwanda, through Student Funding Agency of Rwanda (SFAR). We also thank Ndererimana Vincent, staff of Rwanda Energy Group (REG), for providing technical information despite their responsibilities. The authors also express sincere gratitude to governmental agencies such as Rwanda Natural Resources Authority and Rwanda Meteorological Agency that provided all data used in this study.

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Appendices

Appendix 1. Sieve analysis test results for sediment sample taken at the inlet of the basin.

Sample location: inlet of the basin Dry weight: 1500 g						
1	2	3	4	5	6	7
Sieve size (mm)	Mass of each sieve (g)	Mass of each sieve + retained soil	Mass retained Wi (g)	%retained on each sieve Pi = (Wi/Wt) * 100	Cumulative of %retained Rj = ∑Pi	%finer Nj = 100 − Rj
3.35	484.7	485.4	0.7	0.046	0.046	99.954
2	444.7	447.2	2.5	0.166	0.212	99.788
1.18	418.7	426.4	7.7	0.513	0.725	99.275
0.6	400	486.3	86.3	5.753	6.438	93.522
0.425	378.3	453.165	65.865	4.391	10.144	89.856
0.212	340.2	1280.9	940.7	62.713	88.817	11.143
0.15	327	460.5	133.5	8.9	97.717	2.243
0.075	310.5	341.1	30.6	2.04	99.757	0.20
Pan	386.7	389.7	3	0.2	100	0
Total			**1500**		**100**	

Appendix 2. Sieve analysis test results of sample collected at upstream of the intake.

Sample location: upstream of the basin Dry weight: 1500 g						
1	2	3	4	5	6	7
Sieve size (mm)	Mass of each sieve (g)	Mass of each sieve + retained soil	Mass retained Wi (g)	%retained on each sieve Pi = (Wi/Wt) * 100	Cumulative %retained Rj = ∑Pi	%finer Nj = 100 − ∑Rj
3.35	484.7	539.7	55	3.666	3.666	96.334
2	444.7	559.9	115.2	7.68	11.346	88.654
1.18	418.7	479.3	60.6	4.04	15.386	84.654
0.6	400	511.4	111.4	7.426	22.812	84.614
0.425	378.3	643.7	265.4	17.693	40.505	77.188
0.212	340.2	1182.7	842.5	56.166	96.671	59.495
0.15	327	369.6	42.6	2.84	99.511	3.329
0.075	310.5	316.6	6.1	0.406	99.917	0.489
Pan	386.7	387.9	1.2	0.08	100	0
Total			**1500**		**100**	

Appendix 3. Sieve analysis test results for sample collected at the outlet of the basin.

Sample location: outlet of the basin Dry weight: 1500 g						
1	2	3	4	5	6	7
Sieve size (mm)	Mass of each sieve (g)	Mass of each sieve + retained soil	Mass retained Wi (g)	% retained on each sieve Pi Wi/Wt*100	Cumulative % retained Rj = ∑ Pi	% finer Nj = 100 − ∑Rj
3.35	484.7	484.7	0	0	0	100
2	444.7	444.7	0	0	0	100
1.18	418.7	418.7		0	0	100
0.6	400	400	0	0	0	100
0.425	378.3	485.3	107	7.13	7.13	92.87
0.212	340.2	847.8	507.6	33.84	40.97	59.03
0.15	327	960.5	633.5	42.23	83.2	16.8
0.075	310.5	379.2	68.7	4.58	87.78	12.22
Pan	386.7	387.9	183.2	12.21	100	0
Total			**1500**			

Appendix 4. Hydrometer test results of sample collected at the outlet of the basin.

Elapsed time in min	Room temperature in ˚C	Hydrometer reading Ra	Hydrometer reading after meniscus correction Rh	Effective depth L in cm	Corrected reading Rc = Rh ± Cm	Value of K	Particle size in mm $D = K\sqrt{\frac{L}{t}}$	Percentage finer $\frac{R_c}{W_s} \times 100$
0.25	27	45	45.5	8.85	41.9	0.013	0.073	83.8
0.5	27	44	44.5	9	40.9	0.013	0.056	81.8
1	27	41	41.5	9.5	37.9	0.013	0.041	75.8
2	27	36	36.5	10.3	32.5	0.013	0.03	65.8
4	27	29.5	30	11.3	26.4	0.013	0.0224	52.8
8	27	27	27.5	11.8	23.9	0.013	0.0162	47.8
15	27	24	24.5	12.3	20.9	0.013	0.012	41.8
30	27	21	21.5	12.8	17.9	0.013	0.0087	35.8
60	27	18	18.5	13.25	14.9	0.013	0.0063	29.8
1200	26.5	12	12.5	14.25	8.9	0.013	0.0014	17.8

$Vs = \frac{\gamma_s - \gamma_w}{18\mu} D^2; D = \sqrt{\frac{18\mu}{\gamma_{s-\gamma_w}}} \times \sqrt{V_s}$ Or $D = K\sqrt{\frac{L}{t}}$, where $K = \sqrt{\frac{18\mu}{\gamma_{s-\gamma_w}}}$, Vs = particle settling velocity in cm/s; μ = Viscosity of water in gm·s/cm^2; D: particle diameter in cm; γ_s = unity weight of soil particles; γ_w = unity weight of water; Cm = meniscus correction factor (usually, Cm equals to 0.5 and zero correction factor was found to be 3.5).

Appendix 5. Sand exploitation in Sebeya River.