



Enhancing the resilience of community-led energy systems and mid-hill landscapes in Nepal: Two cases of multi-layered bioengineering

Dry stone walls and bamboo retaining walls on the bank of a stream flowing into the Nisi River in the Baglung district.
Photo by RECOFTC

1. Introduction

Nepal is a country characterized by the frequent occurrence of natural disasters throughout its territory, with geoseismic tectonics, annual torrential precipitation, and climate change impacts being the main causes. The mid-hill regions in Nepal are increasingly experiencing the impacts of climate-induced disasters like flash floods and landslides associated with erratic rainfall patterns. These impacts have a direct effect on rural energy supply systems as micro-hydropower plants (MHPs) are often located along steep slopes and riverbanks. Disruptions in energy supply cause severe chain reactions to local livelihoods, small enterprises, and essential services.

To address these vulnerabilities, the **WISONS Innovation Lab in Nepal**, an energy-landscape nexus initiative implemented by RECOFTC Nepal, was conducted in Baglung and Jumla districts. The initiative's understanding is that energy systems, their infrastructure, and their operations are deeply interconnected with natural components such as water, forests, and the broader landscape. By combining landscape management interventions with renewable energy systems, the initiative aims to reduce disaster risks, demonstrate low-cost replicable bioengineering approaches, and maintain a sustainable and affordable supply of electricity to rural communities.

This comparative case study examines the application of bioengineering practices across two distinct micro-hydropower sites in Nepal: the Girikhola Jalapadevi MHP in Jumla District and the Nisikhola III MHP in Baglung District.

2. Site Description

2.1. Girikhola Jalapadevi MHP (Jumla District)

The Jumla district, located in Nepal's Karnali Province, demonstrates both the opportunities and vulnerabilities of MHP systems. Due to its rugged terrain and remoteness, connecting villages to the national grid is extremely costly, making MHPs vital for local economic development. Commissioned in 2019, the 214 kW Girikhola MHP operates under a cooperative and supplies power to approximately 2,200 households across a 194 km² catchment.

Since 2020, frequent monsoon floods and landslides have caused severe erosion around the powerhouse and intake. Heavy rainfall between October 18 and 20, 2021, triggered sediment-laden runoff and river overtopping. These risks were further exacerbated by human and hydrological drivers:

- **Upstream Roadworks:** Runoff from road construction channels sediment and debris ran directly onto slopes above the facility.
- **Canal Seepage:** A damaged buried canal on private land continuously leaked water, causing waterlogging in fields and directing flow downhill toward the powerhouse.
- **Forebay Overflow:** During high flow, the forebay frequently overflowed directly onto the steep slope above the powerhouse, increasing landslide risks.

2.2. Nisikhola III MHP (Baglung District)

The Nisikhola III MHP in Baglung district was selected under the WISIONS Innovation Lab to demonstrate landscape solutions against flash floods and slope instability. The 100 kW MHP is the source of electricity to around 800 households of Nisikhola rural municipality and has been operating since 2013.

The facility is located in a highly vulnerable zone below two seasonal rivers. During the monsoon season, water flow in these adjacent rivers increases noticeably, exposing the intake and powerhouse to severe inundation and erosion. Furthermore, flushed water discharged from the forebay mixes directly with the seasonal streams, adding significant volume to floodwaters and compounding the threat of structural destruction.

The newly constructed road above these infrastructures and rivers caused massive landslides, directly affecting upstream areas of the forebay and powerhouse. This landslide, when mixed with flood in seasonal rivers, increases the risk of inundation in the powerhouse.

3. Application of bioengineering practices

In the case of slope stabilization and flood prevention, bioengineering measures involve the strategic plantation of native vegetation. This forms a self-sustaining, stabilised structure by binding soil and reducing erosion, while providing additional ecological benefits such as biodiversity enhancement. Multilayered bioengineering practices often combine three types of components: Grasses or shrubs, stone walls or gabions, and shrubtrees.

The bioengineering practices applied in Jumla as well as Baglung will be treated here in turn.

3.1. Interventions at Girikhola MHP (Jumla)

At Girikhola the bioengineering interventions were designed to target the waterlogging from canal seepage, and surface runoff from unengineered road cuts above the MHP facility. A multi-level hybrid approach was implemented to stabilize slopes, protect critical infrastructure and reduce erosion risks:

- **Bamboo Retaining Walls:** Four step-like retaining barriers were constructed using 5-foot bamboo poles set 2 feet deep at 1-meter intervals. Horizontal bamboo layers were tied across the posts and locked with 3-foot bamboo pegs.
- **Bamboo Crib Walls:** Six crib walls (totaling ~70 m³) were constructed in crisscross patterns along unstable slopes upslope of the retaining walls to intercept surface runoff and stabilize soil.
- **Gabion Walls:** A total of 35 gabion walls filled with local river cobbles were installed - 7 directly behind the powerhouse and 28 along the riverbank by the operator's house - to deflect flood energy and prevent scouring.
- **Bamboo Wattling Fences:** Three fences made of woven horizontal bamboo rods between vertical stakes were built behind the powerhouse to filter sediment and slow overland flow.
- **Vegetative Plantation:** Live branches of Bains (*Salix tetrasperma*) and Lahare Peepal (*Populus ciliata*) along with Dhatelo (*Prinsepia utilis*) seedlings were planted on crib walls and slopes.

Jumla Case



Slope before Installation of Crib Wall



After Installation of Crib Wall



Condition of river beside operator house before gabion installation.



Condition after installation of gabion walls

3.2. Interventions at Nisikhola III MHP (Baglung)

At Nisikhola III, interventions were specifically designed to combat hydrological threats caused by two adjacent seasonal rivers overflowing during monsoons, compounded by high-volume forebay flush discharges. A multi-level hybrid system was implemented to manage soil saturation, dissipate stream velocity, and prevent the collapse of slope toes near vulnerable MHP structures. The intervention included the following components:

- **Bamboo Crib Walls:** Nine crib walls were installed along erodible slopes to provide immediate structural support and trap soil movement, with vegetative branches inserted between bamboo layers.
- **Bamboo Retaining Walls:** Twelve retaining walls constructed from bamboo and binding wire were placed below crib walls to support minor ground movement.
- **Dry Stone Walls:** Four mortar-free dry stone walls were placed at ground level below the retaining walls along continuous water flow lines to protect slope toes from river erosion.
- **Gabion Walls:** Approximately 120 m³ of gabion walls were installed across two high-vulnerability sites where vegetation alone could not offer sufficient structural resistance.
- **Vegetative Plantation:** Vegetative branches capable of vegetative propagation - including Khirro (*Sapium insigne*), Bains (*Salix tetrasperma*), Asuro (*Adhatoda vasica*), and Dabdabe (*Garuga pinnata*) - were planted along structural cribs.

While Girikhola MHP (Jumla) relied on tiered slope stabilization and paid labor facing high external procurement costs, Nisikhola III MHP (Baglung) focused on the most vulnerable point of the slope where the slope meets flowing water backed by strong community resource-sharing.

Baglung Case



Slope adjacent to the road above the powerhouse and the channels before intervention



After intervention: Dry stone walls, Bamboo Retaining wall and Bamboo Crib walls are constructed



Bioengineering on the riverside of one of the streams flowing beside the powerhouse



Gabion walls installed for landslide protection above the powerhouse

4. Implementation Process and Economic Aspects

4.1. Institutional Arrangement and Implementation Process

Both projects emphasized stakeholder collaboration involving MHP executive committees, local municipal governments, and provincial Soil and Watershed Management Offices (SWMO).

- **Jumla Logistics:** Bamboo is not locally available at the site in Jumla; it had to be purchased in Dailekh district and transported via regional and local vehicles. Stones were gathered locally from the riverbed. Bioengineering consultants provided on-site technical guidance to local hired laborers.
- **Baglung Logistics:** Materials were procured through bidding managed by the MHP committee. Local communities contributed bamboo directly, while the rural municipality provided stones for gabion filling, significantly reducing procurement complexity and costs.

4.2. Coordination with local stakeholders

- Jumla case: Coordination with the local government and district soil and watershed management office was done prior to the activity implementation. However, there was a gap in communication between these meetings and actual intervention, which caused ineffective coordination with other stakeholders apart from the MHP.
- Baglung case: The district soil and watershed management office was brought for consultation from the planning phase on, which increased ownership of the institution towards the intervention. Similarly, the local government was also informed of the activity prior to implementation. Local MHP committees took the lead in coordinating with the local government, making it easier for them to trust the process. In the end, SWMO provided their technical expertise during planning and implementation, while the local government provided hardware support in the intervention. Local communities were also supported with materials (Bamboo). This shows a clear resource leveraging process in Nisi khola.

4.3. Financial Breakdown (Girikhola Project Case Study)

SN	Particulars	Amount (NPR)	Amount (USD)
1	Bioengineering consultant (design and planning)	170000	1268.66
2	Materials cost	230000	1716.42
3	Materials transport	90000	671.64
4	Excavation cost	25000	186.57
5	Labor cost	295000	2201.49
6	Communication material	10000	74.63
7	Travel cost	100000	746.27
Total Cost		920000	6865.67

(Considering an exchange rate of 1 USD = 134 NPR at the time of intervention, might differentiate from current rates)

The analysis of the USD 6,865 total cost in Jumla reveals key insights about the **high expert mobilization costs of** contracting Kathmandu-based consultants. They accounted for nearly 18% of the budget due to travel distance and single-site assignment. Furthermore, the **remote acquisition of bamboo** from neighboring districts inflated material expenses to roughly 35% of the total budget.

4.4. Financial breakdown (Nisikhola III MHP)

SN	Particulars	Amount (NPR)	Amount (USD)
1	Bioengineering consultant (design and planning)	170000	1133.33
2	Materials cost including transportation	231700	1544.66
3	Excavation cost	50000	333.33
4	Labor cost	401000	2673.33
5	Travel cost	100000	666.67
6	Logistics arrangement	100000	666.67
Total Cost		1052700	7018

(Considering an exchange rate of 1 USD = 134 NPR at the time of intervention, might differentiate from current rates)

As compared to Jumla, labor cost seems higher in this case. But the area of work, including the number of gabions, was more than in Jumla, increasing the working days, and therefore, labor cost. Since bamboo was contributed by the communities, the cost of materials has come down. The analysis shows that 38% of the total intervention cost has gone as labor cost generating employment to the communities, 22% is material cost and 11% is consultant cost including planning as well as technical expertise during implementation.

5. Intervention monitoring and maintenance

After the intervention was completed, an agreement was made between the MHP committee and RECOFTC Nepal where the responsibility to look after maintenance of structures was assigned to the committee. The provision in the agreement also mentioned that the MHP will assign a focal person to look after the structures' maintenance requirement and keep in continuous contact with the RECOFTC team. Along with this, the MHP committee should be responsible to coordinate with the local government as and when required for any other additional activities related to protection of the infrastructures.

After the follow-up with the focal persons, as of June 2026, most of the structures in both sites are still in place, however, very few plants have grown successfully and many dried up. Some of the retaining walls that were constructed above the crib walls have fallen, however, other crib walls and dry stone walls are intact. Thus significant part of the basic structures are still stable (e.g. bamboo crib walls and dry stone walls) this allows for replantation of the vegetable elements. Moreover, technical knowledge for reinforcing or even complementing the destabilized structures is available at the provincial SWMO. However, difficulties to mobilize the needed resources (i.e. technical support, vegetative branches and labour) persists.



a)



b)

Some of the structures in Baglung case by June 2026. a) Bamboo crib walls are still stable but with a low rate of vegetative establishment. b) intact gabion walls.

6. Lessons Learned and Comparative Synthesis

Focus Area	Girikhola MHP (Jumla District)	Nisikhola III MHP (Baglung District)	Key Synthesis & Takeaway
Material Sourcing & Procurement	Bamboo had to be purchased and transported from the neighboring Dailikh district, adding significant logistics costs. Stones were collected locally from the riverbed.	Bamboo was contributed directly by local communities, and the rural municipality provided stones for gabion filling.	Localized resource-sharing and community contributions dramatically reduce procurement costs and build local ownership.
Labor Dynamics & Participation	Surrounding land behind the powerhouse was privately owned, preventing planned vegetative tree planting in those specific zones.	Flexible access across the micro-catchment allowed strategic positioning of structural and vegetative measures.	Land ownership assessments must be conducted during the initial design phase to prevent spatial restrictions during field execution.
Upstream Vulnerabilities & Root Causes	Ongoing leakage from a private irrigation canal continuously destabilized sub-surface slopes behind the powerhouse.	Flushed water from the forebay mixed with seasonal streams, increasing overall flood volume during heavy rainfall.	Vulnerabilities that are beyond the scope of bio-engineering techniques - but which can affect the effectiveness of the project - should be addressed in parallel or previously.
Seasonal Timing & Survival	Construction schedules and transport were disrupted by unexpected heavy monsoon downpours.	Construction occurred late in the seasonal window near winter, lowering initial vegetative establishment rates.	Project planning should take into account both: a) weather seasonality and optimal growth cycles as well as b) some level of flexibility to deal with unexpected disruptions.
Expertise & Scaling Costs	Hiring external experts from Kathmandu for a single site accounted for nearly 29% of the total project budget.	Benefit-sharing and local technical collaboration with municipal/district watershed offices supported execution.	Mobilizing experts across multi-site regional clusters or training local municipal staff prevents high single-site overhead expenses.
Monitoring & Maintenance	Having a focal person at local level who is trusted by the community and also has some local knowledge of the intervention engaged formally from the beginning of the task is important. This allows communities to continuously connect with the project and have ownership over the intervention.	Consultation with the MHP committee before the intervention made it easier for execution in this case. However, even though the agreement was made between the MHP and RECOFTC, the focal person was not specified which became a gap for effective communication. Furthermore, clear responsibilities of the focal person and staff from local and provincial administration should be pre-defined during the agreement process.	Clear and fixed responsibilities for monitoring and maintenance are crucial. They should not rely on a voluntary basis.

The comparison of the two sites that are analysed here reveals several key takeaways:

1. **The site assessments must extend beyond technical factors:** Prior to the design, the conducted feasibility studies must evaluate local committee governance, land ownership, material availability.
2. **Root-Cause Drivers must be detected and addressed:** In Jumla, while bioengineering effectively stabilized surface slopes behind the powerhouse, unresolved canal leakage on private land continuously threatened sub-surface stability. Upstream drivers must be addressed.
3. **There must be multi-site expert integration:** Hiring specialized technical consultants for isolated, single-site projects creates high costs. Integrating expert oversight across multi-site regional programs or training municipal soil and water management staff greatly improves the cost efficiency.
4. **Formal commitments for Monitoring and Maintenance:** Post-construction monitoring showed low levels of plant survival in both cases due to seasonal stress. Moreover, standard maintenance tasks haven't been executed in any of the cases. Future initiatives must incorporate formal agreements for undertaking the required maintenance and replacement.
5. **Including at least one maintenance cycle into the project execution period.** The needed know-how for maintenance is locally available, as it encompasses similar procedures applied during the construction. However, the regular practice of coordinating and mobilizing actors for the maintenance appears to be a crucial barrier for sustainability. Supporting at least one maintenance cycle may help in establishing such practice.

7. Recommendations for Future Interventions

Several recommendations for future bioengineering interventions can be taken away from the example in Jumla and Baglung treated in this comparison:

- **Incentivization of local ownership:** Link bioengineering interventions to local livelihood training to strengthen community participation and ensure long-term care of structures.
- **Prioritize native living species:** Emphasize local species like *Salix* (Bains) that adapt well to local soil conditions and can regenerate vegetatively through structural cribs and retaining walls.
- **Incorporate weather contingencies in planning process:** Build flexible construction timelines with buffer periods to avoid seasonal planting failures during early frost or heavy monsoon rains.
- **Ensure solid local capacities for ex-post maintenance:** Build clear arrangements with relevant local actors about roles and responsibilities for the monitoring and maintenance of the interventions. Incorporate at least one ex-post maintenance campaign within the project period in order to accompany and - if needed - reinforce local capacities.
- **Enforce infrastructure standards:** Unplanned rural road construction, slope cutting without stabilization, and poor drainage severely exacerbate landslide and flood risks. Strict geological and environmental standards must be mandated prior to rural road construction.
- **Implement risk mapping and early warning systems:** Government agencies should prioritize mapping high-vulnerability flood/landslide zones around decentralized energy infrastructures and install early warning systems.
- **Promote nature-based solutions:** Integrate cost-effective bioengineering guidelines into municipal infrastructure policy to allow local communities and MHP cooperatives to replicate slope protection independently using local resources.



Community meeting for coordinating the construction work in Nisi Khola. Picture: Recoftc

This case study is part of the series “Sustainability Solutions for Mountain People and Landscapes,” developed within the WISIONS Innovation Lab Nepal. The aim is to promote an integrated approach to strengthening the livelihoods of people living in mountain communities. Each factsheet provides information on specific sustainability solutions in the fields of energy and landscape management that have shown promising potential or improving the livelihoods of mountain people but have a low level of adoption in Nepal and other mountain regions. The information is tailored to the specific context of Nepal’s mountain landscapes and offers practical insights and guidance for scaling up the application of these solutions. Additionally, it presents an integrated approach that begins with an understanding of the opportunities and challenges faced by mountain communities, enabling the systematic deployment of synergies between solutions from the energy and landscape sectors.

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