Quantifying Energy Generation Loss: A Comparison Of Conventional And Bieri Vertical Sediment Flushing Systems In Himalayan Hydropower Projects

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Abstract

In The efficiency, dependability, and longevity of hydropower plants are seriously threatened by high silt loads in Himalayan Rivers, which result in severe turbine abrasion and frequent operational shutdowns. The Bieri Vertical Sand Flushing System (BVFS) at the Middle Marsyangdi Hydropower Project (MMHPP) and Conventional Sediment Flushing Systems (CSFS) at the Upper Trishuli 3A Hydropower Project (UT3A) are compared in this study.
The primary objective was to test the performance of the two systems on cost, sediment removal, and the functioning of the system under the conditions within the Gandaki Basin of Nepal. The quantitative case study design was applied in the study where three years of operating data, site visit, and primary data was used to trace the downtime, energy loss and maintenance cost. The outcomes are clear that BVFS is more effective in its operation. It suffered zero forced outages in the flushing process but the CSFS experienced approximately 273.69 hours of unavailability in the same period. The water consumed by BVFS was also approximately half as much and its energy loss was almost 85 percent less than that of the routine horizontal flushing technique. With a higher initial cost of about the NPR 400 million, BVFS proved to be financially sustainable, with payback of 18.21 years the main reason being in savings on energy and maintenance annually. Generally, the results indicate that BVFS is a good alternative in the control of sediment in high-head projects in heavy sediment zones. It enables power production to be maintained even on peak months of monsoon. According to this, BVFS should be given priority during new projects having high sediment loads and old plants experiencing frequent silt related shutdowns should seriously consider retrofit.

Keywords: Bieri Vertical Sand Flushing System (BVFS); Conventional Sediment Flushing System (CSFS); Middle Marsyangdi Hydropower Project (MMHPP; Upper Trishuli 3 A Hydropower Project (UT3AHPP); Sediment Management; Turbine Abrasion; Flushing Efficiency; Maintenance Cost Analysis; Energy Generation Loss

1. Introduction

Hydropower is the backbone of Nepal's energy system, producing more than 90% of the nation's electrical generation. The Himalayan area, where steep topography, delicate geology, and heavy monsoon rainfall result in exceptionally large sediment loads, is home to the majority of Nepal's hydropower plants. The Rivers Marsyangdi, Kali Gandaki, Trishuli, and Sunkoshi contain some of the world's highest concentrations of sand and sediment. This directly impacts the efficiency and performance of hydro-power plants.
Functional challenges associated with sedimentation include erosion of turbine parts, reduction in hydraulic efficiency, wear and tear of electromechanical equipment, blocking of waterways, and periodic plant shut-

down for maintenance. To counter these issues, different sediment management schemes in the form of settling basins, flushing tunnels, silt excluders, or advanced flushing technologies are used by the companies involved in the development of hydropower.

Of these, the Bieri Vertical Sand Flushing System, which has been installed at Middle Marsyangdi Hydropower Project, is considered to be a reasonably modern and efficient method in which the silt is evacuated vertically prior to its entry into the turbine intakes. The Conventional Sediment Flushing Systems installed at Upper Trishuli 3A, on the other hand, mainly involve the evacuation of sediments horizontally with the aid of desilting basins and flushing gates.

This comparison between BVFS and CSFS is both relevant and necessary, especially in the context of Nepal's rivers being laden with sediment and being prone to extreme weather and floods.

2. Objective

This study's main objectives is to calculate and compare the energy spill due to flushing of desander of both Bieri Vertical Flushing System and Conventional Sand Flushing System.

3. Study Area

Middle Marsyangdi Hydropower Station (MMHPS) is a 70 MW peaking run-of-river (PRoR) project located in Siudibar, Lamjung District, Gandaki Province. The project diverts water from the Marsyangdi River, whose headwaters originate from Tilicho Lake in Manang. The plant is capable of providing up to five hours of daily peaking operation, even during low-flow periods.The project was inaugurated on 14 December 2008 and entered commercial operation one month later.

Upper Trishuli 3A Hydropower Station (UT3A HPS) is a 60 MW run-of-river (RoR) hydropower project located at the border of Rasuwa and Nuwakot districts, Bagmati Province, Nepal. The plant comprises two vertical Francis turbines, each rated at 30 MW, operating under a gross head of 144.5 m and a design discharge of 51 m^3/s (25.15 m^3/s per unit).Commercial operation began in May 2019 (Unit 1) and August 2019 (Unit 2).

Sampling Techniques:

Purposive Sampling will be applied, as the selection of projects is based on unique sediment flushing methods.

Sample Plants:

- BVFS: Madhya Marsyangdi HPP (70 MW).
- CSFS: Upper Trishuli 3A (60 MW).

Criteria for selection:

- Location within the Gandaki Basin.
- Similar sediment load environments (glacial and monsoon-fed rivers).
- Data availability for at least 1–2 years.

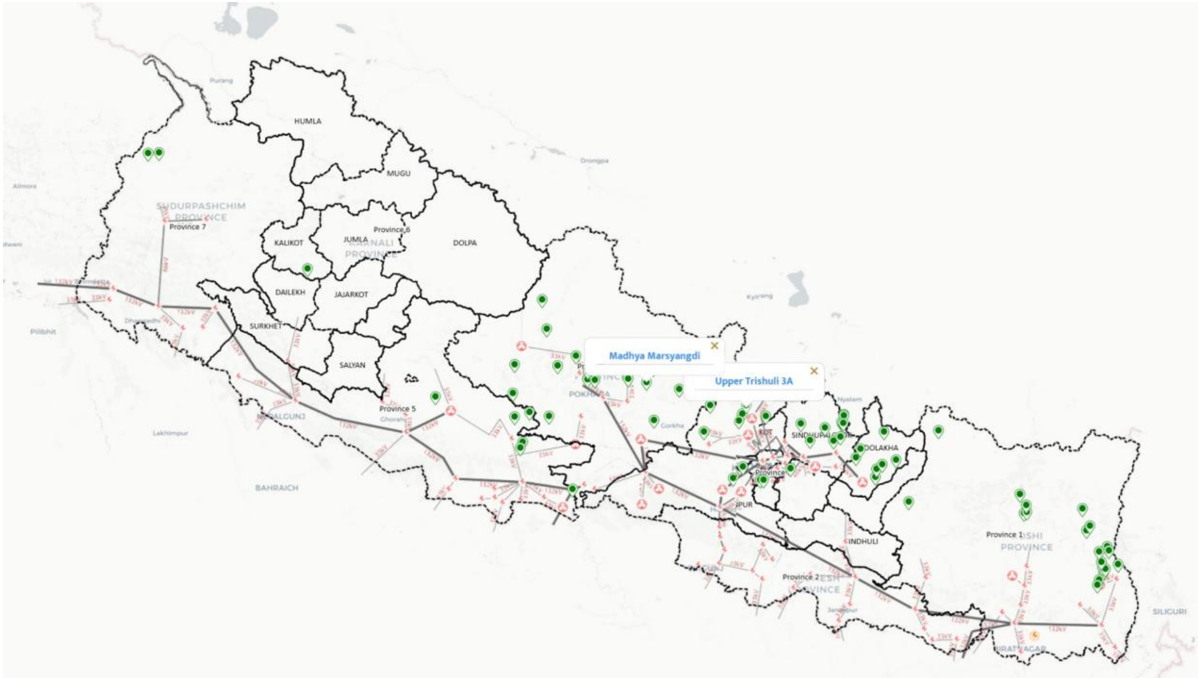

Fig. 1. Figure of Study Area;

4. Methodology

1) Starting the Research
   a) The study ensures that the research objectives, scope, and methodology are feasible and academically valid.
2) Literature Review
   a) A comprehensive examination of the international and Nepal-related literatures pertaining to sediment management, erosion of turbines, and flushing systems.
   b) The base this establishes is good for spotting gaps in literature and for giving a reason for the comparison study between BVFS (Madhya Marsyangdi) and CSFS (Upper Trishuli 3 A Hydropower Project (UT3AHPP)).
3) Work Permit from Nepal Electricity Authority, MMHPP & UT3AHPP
   a) Formal permissions are obtained from NEA, project sites, and supervisors for access to operational data, sediment information, and hydropower plant visits.
   b) Access to the site is important because the plants in the Gandaki Basin have delicate infrastructure.
4) Materials Preparation
   The resources are prepared, and these include
   a) Historical sediment concentrations data (ppm, particle size distribution).
   b) Records concerning the maintenance of turbines (abrasion frequency,
   c) Records regarding energy production (plant factor and monsoon outages).
   d) Hydrological data (River discharge, flood information)

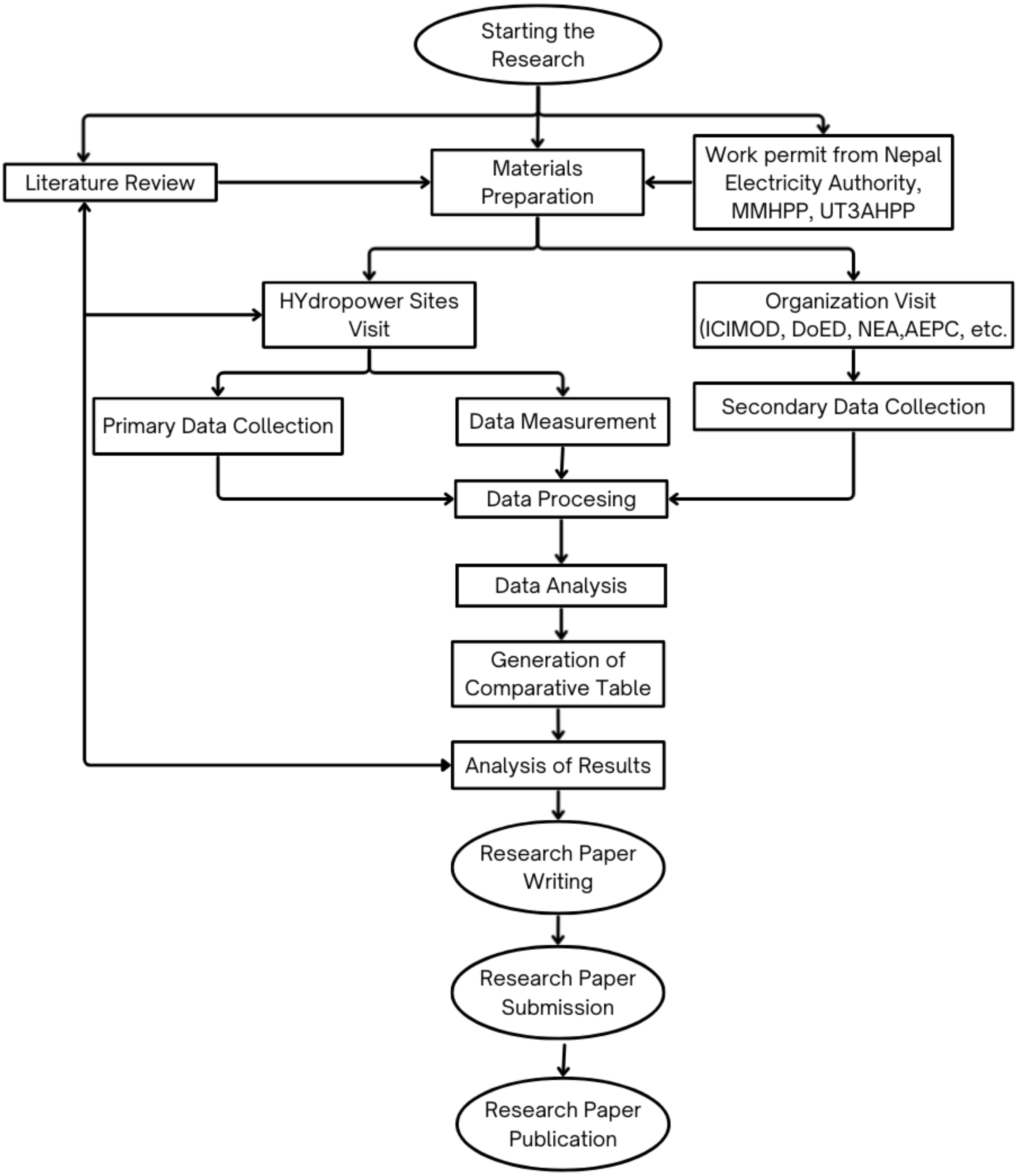

Fig. 2. Methodology Flow Chart;

5. Results and Discussion

This study's main objectives is to calculate and compare the energy spill due to flushing of desander of both Bieri Vertical Flushing System and Conventional Sand Flushing System.

5.1. Energy Spill Due to Flushing

5.1.1. Energy Spill Due to Flushing in Conventional Flushing System (UT3A)

Table 1. Energy Spill Due to Flushing in Conventional Flushing System (UT3A)

Year & Month	Total Outage in hour during Flushing (CSFS)	Total Energy Loss in KWh (CSFS)	Total Loss in Rs. (CSFS)
2079 Ashar	17.63	528,900	3,173,400
2079 Shrawan	47.68	1,430,400	8,582,400
2079 Bhadra	4.45	133,500	801,000
2079 Ashoj	5.12	153,500	921,000
2080 Jestha	16.65	499,500	2,997,000
2080 Ashar	23.3	699,000	4,194,000
2080 Shrawan	6.88	206,500	1,239,000
2080 Bhadra	22.65	679,400	4,076,400
2080 Ashoj	2.52	75,500	453,000
2081 Ashar	23.78	713,400	4,280,400
2081 Shrawan	47.8	1,433,910	8,603,460
2081 Bhadra	27.701	831,030	4,986,180
2081 Ashoj	27.53	826,110	4,956,660

(Source: UT3A Flushing Report)

5.1.2. Energy Spill Due to Flushing in Bieri Vertical Flushing System (MMHPP)

Table 2. Energy Spill Due to Flushing in Bieri Vertical Flushing System (MMHPP)

Year & Month	Flushing Duration in minutes in respective month (BVFS)	Volume of water (m^3) loss per minute during Flushing (BVFS)	Total Volume of water loss (m^3) during Flushing (BVFS)	Total Energy Loss in KWh (BVFS)	Total Revenue Loss in NPR Rs. (BVFS)
2079 Ashar	1,336.5	32.03	42,800	79,340	476,040
2079 Shrawan	3,615.0	32.01	115,700	214,560	1,287,360
2079 Bhadra	337.5	32.00	10,800	20,030	120,180
2079 Ashoj	390.0	31.79	12,400	23,030	138,180
2080 Jestha	1,260.0	32.06	40,400	74,930	449,580
2080 Ashar	1,770.0	31.92	56,500	104,850	629,100
2080 Shrawan	525.0	31.81	16,700	30,980	185,880
2080 Bhadra	1,725.0	31.88	55,000	101,910	611,460
2080 Ashoj	195.0	31.28	6,100	11,330	67,980
2081 Ashar	1,800.0	32.06	57,700	107,010	642,060
2081 Shrawan	3,630.0	31.96	116,000	215,090	1,290,540
2081 Bhadra	2,100.0	32.00	67,200	124,650	747,900
2081 Ashoj	2,085.0	32.04	66,800	123,920	743,520

(Source: MMHPP Flushing Report)

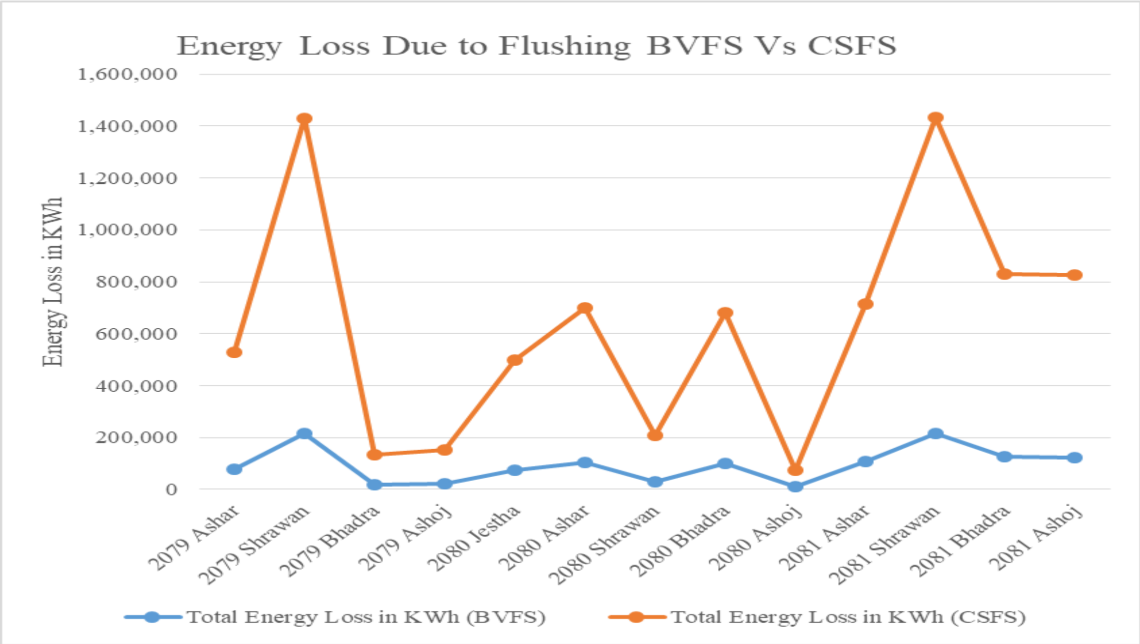

Fig. 3. Line Graph of Energy Loss Comparison Due To Flushing;

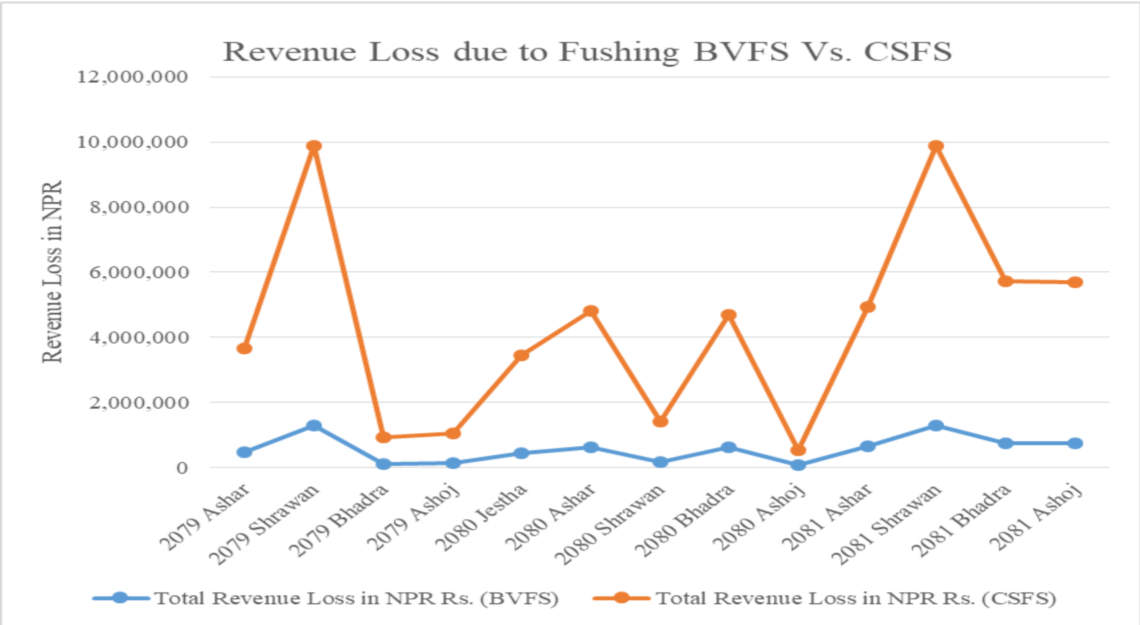

Fig. 4. Line Graph of Energy Loss Comparison Due To Flushing;

5.1.3. Data Summary (3-Year Analysis Period)

Table 3. Data Summary (3-Year Analysis Period)

System	Total Plant Outage Hours During Flushing	Total Energy Loss (kWh)	Total Financial Loss (NPR)
CSFS (UT3A)	273.391 hours	8,210,650 kWh	49,263,900 NPR
BVFS (MMHPP)	0 hours	1,231,630 kWh	7,389,780 NPR

5.1.4. Payback Period Calculation

Capital Cost Differential:

- BVFS installation: NPR 650,000,000
- CSFS installation: NPR 250,000,000
- Additional investment for BVFS: NPR 400,000,000

Annual Savings from BVFS:

- Direct savings on energy loss: NPR 13,958,040/year
- Additional O&M savings: NPR 8,000,000/year (30-40% lower maintenance)
- Total annual savings: NPR 21,958,040/year

Simple Payback Period:

$$\text{Payback Period} = \frac{\textit{Additional Investment}}{\textit{Annual Savings}} = \frac{400{,}000{,}000}{21{,}958{,}040} = 18.21 \text{ years}$$

5.1.5. Sensitivity Analysis

Table 4. Sensitivity Analysis Table

Scenario	Annual Savings Variation	Payback Period
Base Case	NPR 21.96 million	18.2 years
Conservative (10% less savings)	NPR 19.76 million	20.2 years
Optimistic (20% more savings)	NPR 26.35 million	15.2 years
High Sediment Year	NPR 30.0 million	13.3 years

6. Comparison Table

This study's main objectives is to calculate and compare the energy spill due to flushing of desander of both Bieri Vertical Flushing System and Conventional Sand Flushing System.

Table 5. Comparison of BVFS and CSFS

Feature / Performance Metric	Bieri Vertical Sand Flushing System (BVFS)	Conventional Sediment Flushing System (CSFS)
Reference Plant	Middle Marsyangdi (MMHPP)	Upper Trishuli 3A (UT3A)
Operating Principle	Silt is collected by vertical evacuation through basin floor shafts before it reaches turbines.	Horizontal evacuation using low-level flushing valves and settling basins.
Total Plant Outage Hours (3-Year Period) During Flushing	0 hours.	276.75 hours.
Total Energy Loss (3-Year Period)	1,231,630 kWh.	8,210,650 kWh.
Total Financial Loss (3-Year Period)	7,389,780 NPR.	49,263,900 NPR.
Flushing Efficiency	95% for particles $\geq$ 0.2 mm.	85% for particles of 0.13 mm fall diameter.
Water Consumption	Compared to horizontal systems, about 50% less flushing water is used.	Increased water loss is necessary for horizontal scouring to be successful.
Estimated Capital Cost	NPR 650,000,000.	NPR 250,000,000.
Annual O&M Savings	NPR 8,000,000 (30–40% lower maintenance costs).	Increased expenses as a result of regular turbine maintenance and deterioration.
Operational Impact	Permits constant power production while flushing.	Plant shutdowns are frequently required during periods of heavy sediment influx.

7. Assumption and Limitations

The assumption and limitations of this research for simplifying the modeling and are:

- The research will only focus on hydroelectric power stations in the Gandaki Basin, and this means it cannot be generalized to other basin regions to a large extent.
- Variations in plant capacity, turbine type, and operating plans may impact the results despite best efforts to account for them.
- The study will concentrate on short- to medium-term performance metrics; it might not adequately account for long-term effects like structural deterioration over decades

8. Conclusions and Recommendations

8.1. Conclusions

All Several important findings are drawn from this comparative analysis of the Gandaki Basin's sediment flushing systems:

8.1.1. Performance Superiority of BVFS

Compared to conventional systems, the Bieri Vertical Flushing System exhibits definite operating advantages:

- Energy generation loss during flushing operations was reduced by 85% (8.2 GWh vs. 1.23 GWh over 3 years).
- There were no forced outage hours, while CSFS had 273.691 hours.
- Minimal fluctuation in performance over the monsoon seasons
- Removal of fine sediment with 95% efficiency for particles larger than 0.2 mm

8.1.2. Economic Viability

BVFS is more cost-effective even with a larger initial investment:

- Depending on the analysis method, a payback period of 13.3-18.2 years
- An annual savings of more than NPR 21.96 million due to lower maintenance and energy losses
- A favorable lifespan cost-benefit ratio, particularly for Himalayan rivers that are rich in sediment

8.1.3. Environmental and Operational Benefits

- A 40–50% decrease in water loss per flushing event
- The ability to generate power continuously while flushing
- Automated, controlled activities reduce mechanical stress on infrastructure.
- Better removal of fine sediment for turbine protection

8.2. Recommendations

8.2.1. for Hydropower Developers & Investors

8.2.1.1. New Project Development:

- Give BVFS top priority for projects in rivers with silt concentrations more than 5000 parts per million.
- Rather than solely focusing on capital costs, it would be better to use lifespan cost analysis.
- Allocate a sufficient fund for advanced sediment management practices (3-5% of the project cost).

8.2.1.2. Project-Specific Considerations:

- High Head Francis turbines (>100m head): Due to vulnerability to sediment abrasion, BVFS is strongly recommended.
- Peaking plants: As BVFS retains less generation during the flushing process, it is highly preferred.
- Remote Locations: Although the initial transport costs would be higher, it is important to consider the reduced O&M costs of BVFS itself.

8.2.2. for Plant Operators & NEA

8.2.2.1. Operational Optimization:

- Use sediment concentration monitoring to inform predictive flushing.
- Create maintenance procedures tailored to BVFS parts (servomotors, aperture plates).
- Train the operators on complex SCADA controls.

8.2.2.2. Performance Monitoring:

- Establish standardized methods of evaluating sedimentation management systems.
- Establish a common database of maintenance and down times related to sediment.
- All flushing systems should undergo periodic efficiency tests every two to three years.

8.2.3. for Policy Makers & Regulatory Bodies

8.2.3.1. Standards & Guidelines:

- Add sophisticated technologies like BVFS to sediment management recommendations.
- Incorporate energy loss measurements into evaluations of operational and environmental compliance.
- Create systems to encourage the use of effective sediment control techniques.

8.2.3.2. Research & Development:

- Find Comparative studies that compare other river basins (Koshi, Karnali).
- Encourage the adaptation of technology to different sediment properties
- Encourage hydropower operators to exchange knowledge.

8.2.4. for Existing CSFS Plants

8.2.4.1. Retrofit Considerations:

- Explore the retrofit ability of BVFS in plants that are experiencing:
    - High rates of turbine abrasion (>2 mm/year erosion)
    - Regular monsoon shutdowns (more than 50 hours annually)
    - Reduced plant factor as a result of silt problems
- Give strategic plants with a capacity of more than 50 MW priority for retrofitting.
- The majority of units impacted by sediment should be implemented first.

9. Objective

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