

Impact of Hydro Peaking Operation on Downstream RoR Energy Generation in West Seti River Basin

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Abstract

Nepal's power system is dominated by run-of-river (RoR) hydropower projects, challenging load management during peak hours. Amidst prioritization of government policy to Peaking RoR scheme, there is a lack of proper framework for analyzing downstream linkages of hydro-peaking in a river basin. Daily peaking operation of a RoR project will have substantial impact on downstream project but has been less considered in regional studies. This study analyzes the impact of peaking operation on flow availability and subsequent energy generation considering two projects; Chainpur Seti and Seti-Nadi3 HPP of West Seti river basin. This study analyzes two operational scheme; one with complete stoppage of upstream plant for reservoir filling and another reservoir filling by continuous withdrawn on non-peak hours for storage. For the operation Scheme 1, during normal condition the generation loss is 17%, 19% while considering the flushing effect, 16.9% when turbine operation is considered, and 19.2% when both flushing and turbine operation are taken in consideration. Similarly, for operation Scheme 2, the generation loss is 0.97% for normal condition, 3.3% when flushing effect is considered, 0.36% when turbine efficiency only is considered, and 2.8% when both the flushing effect and turbine operation is taken into account. Also, the generation of downstream project shows increasing trend only when the peaking hours is greater than or equal to 2hr. Our study necessitates the multi-stakeholder collaboration in planning and operation at project and basin level for sustainable water resources management.

Keywords—Hydropower, Energy, RoR, PProR, West Seti, Downstream Impact

1. INTRODUCTION

Hydropower developments around the world have been growing and greening the world's electricity supplies by generating clean, reliable and cost-effective power from rivers. Renewable hydropower will remain one of the major sources of electricity production in future as well. Nepal is rich in water resources. If this natural resource is properly harnessed, it can generate enormous hydropower. Hydropower can play important role in

overall development of Nepal because of its huge potential. With increasing demand, the supply also needed to be upsurged. Hydropower plays significant role, as more than 96% of installed capacity currently comes from hydropower sources (NEA, 2023). Though Nepal has enormous hydropower potential, not all of it is economically viable. The technical potential is estimated to be around 83000 MW, while economical feasibility is limited to 42000 MW only (Shrestha, 2017).

Nepal aims to generate 28,500 MW of electricity by 2035 AD. To achieve this goal the government have emphasized the development of storage/ pumped storage projects and peaking RoR projects along with the conventional RoR project (T.N. Bhattarai, 09 Feb 2022). As most of the hydropower projects are of run-of-the-river type, the demand of electricity has not been fulfilled due to the reduction in generation capacity during winter with the decrease in the flow of water in rivers. Government is encouraging developers in shifting from conventional RoR design to peaking capacity scheme, driven by requirement for power purchase agreement. But, there is a lack of proper framework for analyzing upstream-downstream linkages of hydro-peaking in a river basin. Limited studies have been carries out analyzing the potential impact of water collection at hourly scale within a day. Such peaking operation of a PProR project will have substantial impact on downstream project.

In single basin there are multiple ongoing hydropower projects either operating, under construction phase or proposed. Most of the existing studies of hydropower projects in Nepal is concerned with the performance of individual project, totally surpassing the interdependency nature of upstream project with that of downstream projects. In case of large project on the upstream, there is significant alterations in the natural flow of the river, leading to negative impacts on performance and efficiency of downstream projects. With the rapid emphasis in development and construction of PProR project, there is an urgency to develop framework to study the impact of upstream PProR project on the downstream PProR project.

We address this gap by demonstrating the integrated methodological framework for downstream impact assessment in West Seti river basin. This study aims to achieve the following specific objectives: i) To determine the generation impact on downstream project due to upstream project, and ii) To optimize the peaking hours for the considered hydropower plants.

2. MATERIALS AND METHODS

A. Study Area

The West Seti River basin, subbasin of Karnali is one of the major sources of fresh water located in the far western region of Nepal. This region is blessed with monsoon climate. The large portion of precipitation fall between May and June caused by southwest monsoon. The West Seti River spans across an area of approximately 7438 km² and it flows towards south joining Karnali River and later merges with Ganges

Basin in India. The energy output obtained from developing the reservoir project in West Seti River Basin can provide significant benefit on the overall energy generation of country. Hence this basin is selected for this study as it can show the interdependency nature among stakeholders.

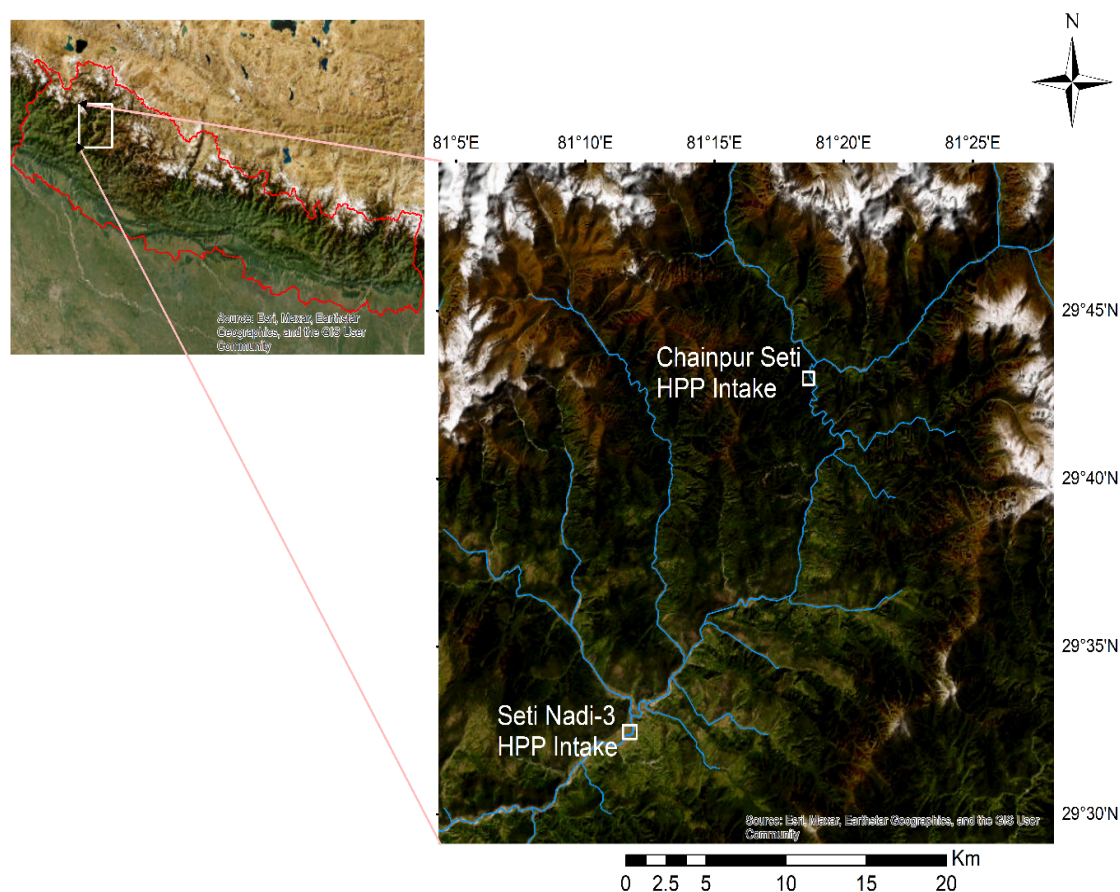


Figure 1: Study area map showing location of intake sites of the considered project

Chainpur Seti Hydropower project (CSHP) is located in Seti River of Bhajang District, Dhamena Melbisauni Village, Bhajang District, Sudurpashim Province, Nepal. The CHSP is a Peaking Run-of-River (PRoR) type with design discharge of $50 \text{ m}^3/\text{s}$ and installed capacity of 210 MW (NEA, A year in Review Fiscal Year 2023/2024, 2023). After the power production, water from the powerhouse is discharged back into the Seti River (Chilime Engineering & Services Co. Ltd.(CHESCO)).

Seti Nadi-3 Hydropower project (SN3HP) is also located at Seti River of Jayprithvi Municipality, Bhajang District, Sudurpashim Province. The design discharge of project is $84.6 \text{ m}^3/\text{s}$ with installed capacity of 87 MW. This is also Peaking Run-of-River type.

The physical features of the hydropower components that are considered in the study are shown in Table 1.

Table 1: Salient Features of hydropower projects

Description	Upstream Project (CSHP)	Downstream Project (SN3HP)
Catchment Area at Intake Site	1390.38 km ²	2265.47 km ²
Annual Rainfall	1561.27 mm	1578.77 mm
Design Discharge	50 m ³ /s	84.6 m ³ /s
Minimum Monthly Flow	14.76 m ³ /s	23.4 m ³ /s
Maximum Monthly Flow	195.54 m ³ /s	310.7 m ³ /s
Minimum Environmental Release	1.47 m ³ /s	2.34 m ³ /s
Gross Head	502.4 m	126.76 m
Net Head	492.6 m	110.35 m
Installed Capacity	210 MW	87 MW
Turbine	Vertical Axis Francis Turbine of 3 units.	Vertical Axis Francis Turbine of 3 units.
Turbine Efficiency	87.5 %	87.5%

B. Datasets

The hydrological data that is used in this study is accessed from DHM. Hydrological review of both upstream and downstream project was conducted from data collected from Gopaghat Station (Station no. 259.2, Catchment area: 4386 km²). Catchment area delineation was performed in ARC GIS. Monthly flow of upstream project is calculated considering hydrological station data at Gopaghat station. And for downstream project mean monthly flow from feasibility report was adopted. The study of both projects is done independently for uniform flow calculation in both projects.

C. Methodology

The overall methodological framework used in this study is shown in Figure 2. This study incorporates streamflow assessment, hydropower energy model, and operational scenarios to quantify the downstream impact of upstream PRoR project, as explained in following sub-section.

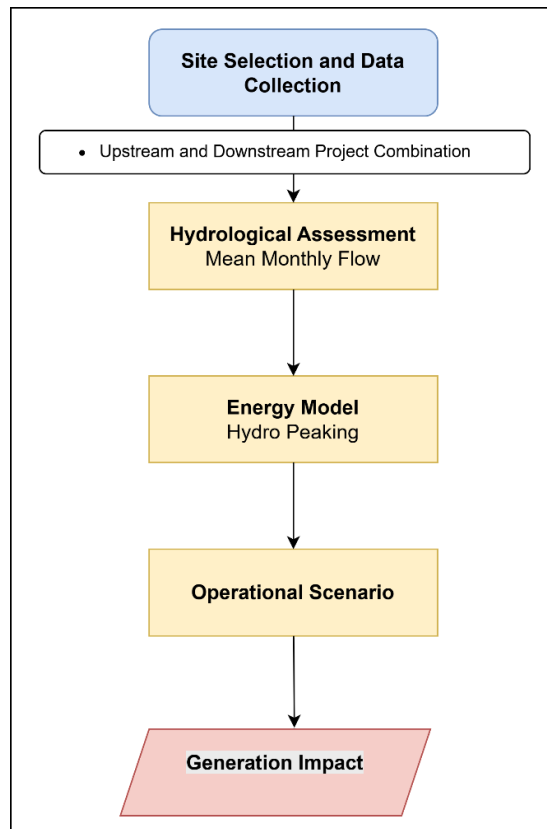


Figure 2: Overall methodological framework used in this study

a. Hydrological Assessment

Storage volume for different peaking hours, barrage height calculation etc. has been done. The total energy for different scenario is calculated. Calculating the total energy output of a hydroelectric power project involves several key factors related to the water flow, head (vertical drop), and efficiency of the system.

b. Hydropower Energy Model

The formula for calculating the total energy output from a RoR HPP is:

Total Energy (Wh) = Flow (m³/s) × Head (m) × Efficiency × 9.81 (acceleration due to gravity) × Time of Operation (hr)

Here, flow (Q) represents the flow rate, critical factor that determines the amount of water passing through the hydroelectric turbine. It is calculated by deducting environmental release from available streamflow and later limited by design discharge. Head (H) is the head difference representing the vertical distance between the water source (weir/dam) and the turbine. Efficiency of the hydroelectric system takes into account losses due to friction, turbulence, and mechanical inefficiencies in the turbine and generator.

c. Impact Assessment Scenario

For the simulation of downstream project, upstream project is assumed to be operated at two different scenarios. For further analysis impact of turbine efficiency as well as flushing impact are also considered for both scenarios case. The detail of these scenarios is described below:

i. Scheme 1 (Complete stoppage of upstream plant during reservoir filling)

In this scenario the water required to meet the peak demand is stored by complete stoppage of upstream plant during reservoir filling after releasing e-flow. During this period the downstream plant is shutdown and hence there is losses in generation of downstream plant.

ii. Scheme 2 (Reservoir filling of upstream plant by continuous withdraw of water during non- peaking hours)

While in this scenario the water required to meet the peak demand is collected by continuous withdraw of water during non-peaking hours. The excess water is left back in the river for downstream project to generate electricity, hence during this time period the downstream project is not completely shut-down but still it cannot perform efficiently like it was supposed to as mentioned in its feasibility study report.

3. RESULTS

A. Flow Regime

The maximum discharge of the U/S project, D/S project is 195.5 m³/s and 310.7 m³/s respectively at the month of August and minimum flow of U/S, D/S project is 14.7 m³/s and 23.4 m³/s respectively in the month of February. For this study the design discharge of the projects has been adopted as per the respective feasibility study of the projects. The design discharge of 50 m³/s has been considered as the design discharge of upstream project and for downstream project the design discharge adopted is 84.6 m³/s.

B. Generation Impact

a. Scheme 1

The bar graph shown in Figure 3, presents the annual generation of downstream project i.e. SN3HP for different scenarios under scheme 1. Here we can see for every scenario the energy generation reduce from that of design energy. In percentage, the annual energy generation is less than 17%, 19% and 19.2% respectively for normal operation, when considering flushing and when both flushing and turbine operation is considered.

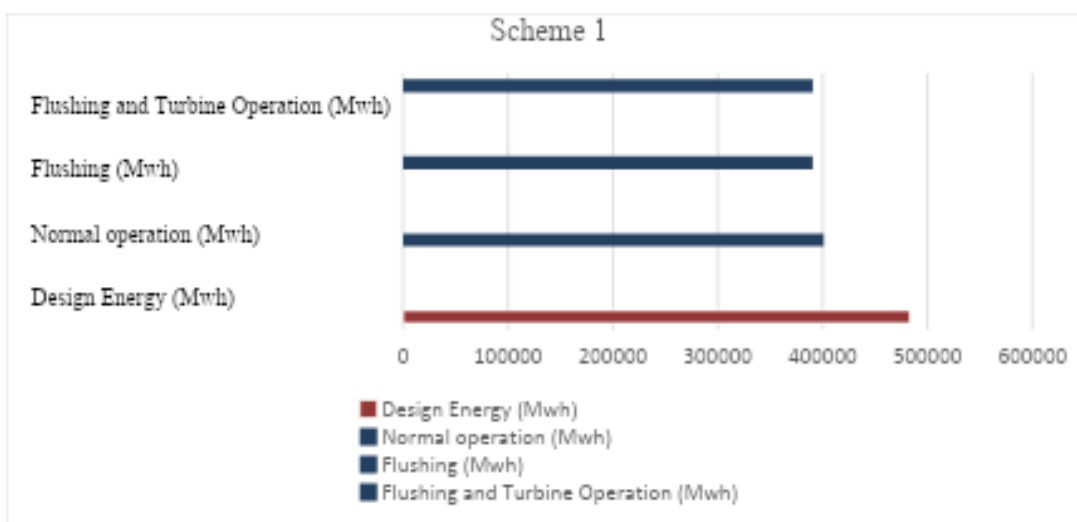


Figure 3: Results of different scenarios under scheme 1

b. Scheme 2

Considering reservoir filling through withdrawing water during off-peak hour, to meet the peak hour demand; the annual generation is somehow more than that from scheme 1. The reduction in annual energy generation of SN3HP while considering scheme 2 limits to 0.97%, 3.3% and 2.8% respectively for normal operation, when considering flushing and when both flushing and turbine operation is considered.

The energy generated by SN3HP while considering Scheme 2 is shown in Figure 4.

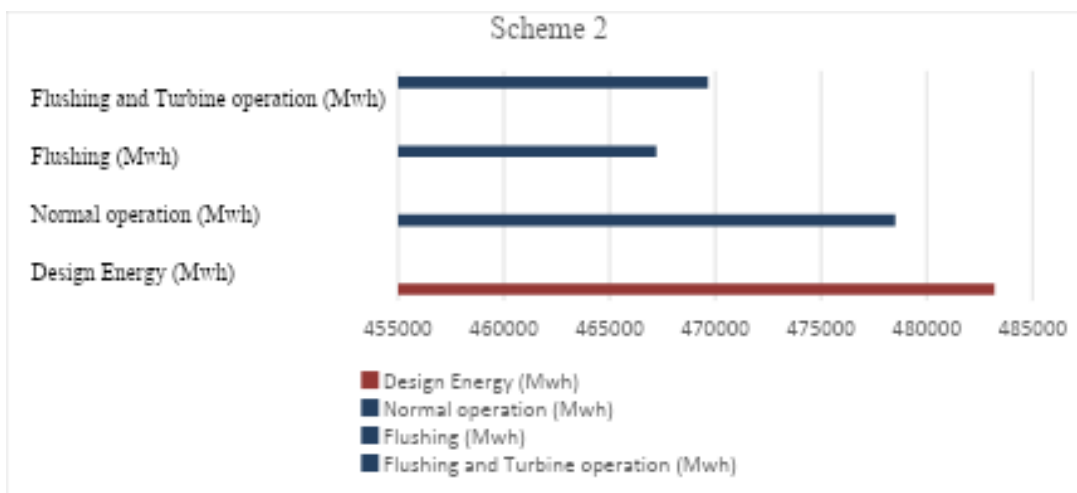


Figure 4: Results of different Scenarios under Scheme 2

c. Considering Flushing

During the monsoon season, the upstream project needs to flush the sediments from the settling basins or barrage gates in the event of flood. In that case the downstream project also simultaneously needs to flush the sediments, cause at that time the

concentration of sediments in the water becomes high leading to shutting down of downstream project.

The energy simulation considering flushing in scheme 1 and scheme 2 is shown in Figure 5.

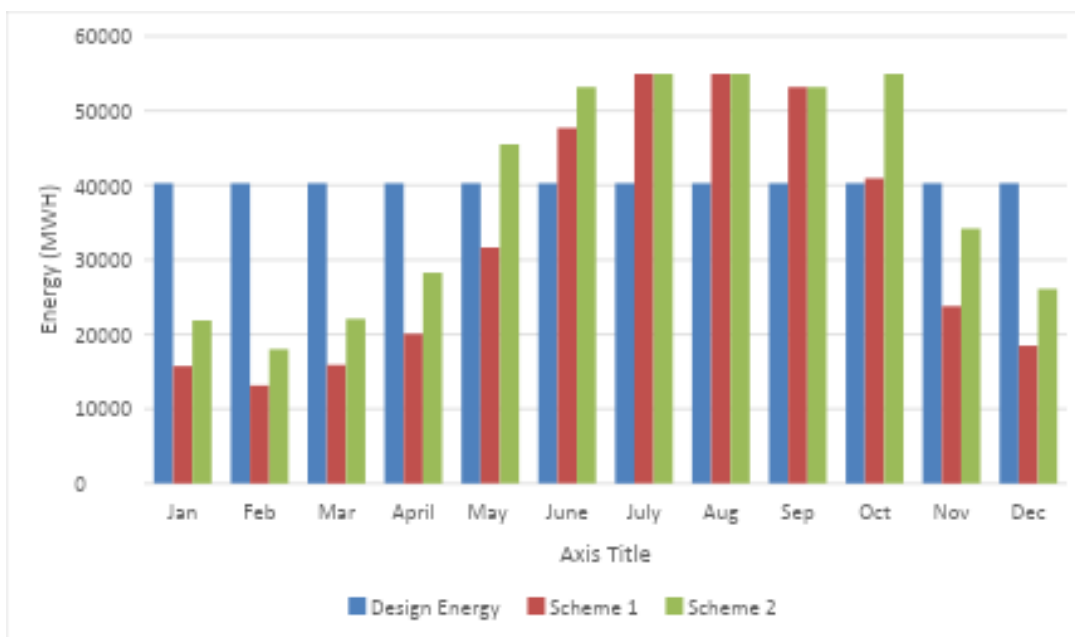


Figure 5: Energy comparison chart considering flushing

d. Considering Flushing and Turbine Operation

The generation from hydropower plant is generally dependent on the discharge and efficiency of turbine's operation. Excessive discharge can lead to turbine overload and damage to hydropower facilities, while insufficient discharge can result in insufficient generation.

The result obtained while considering effect of both flushing and turbine operation for both scheme 1 and scheme 2 is shown in Figure 6.

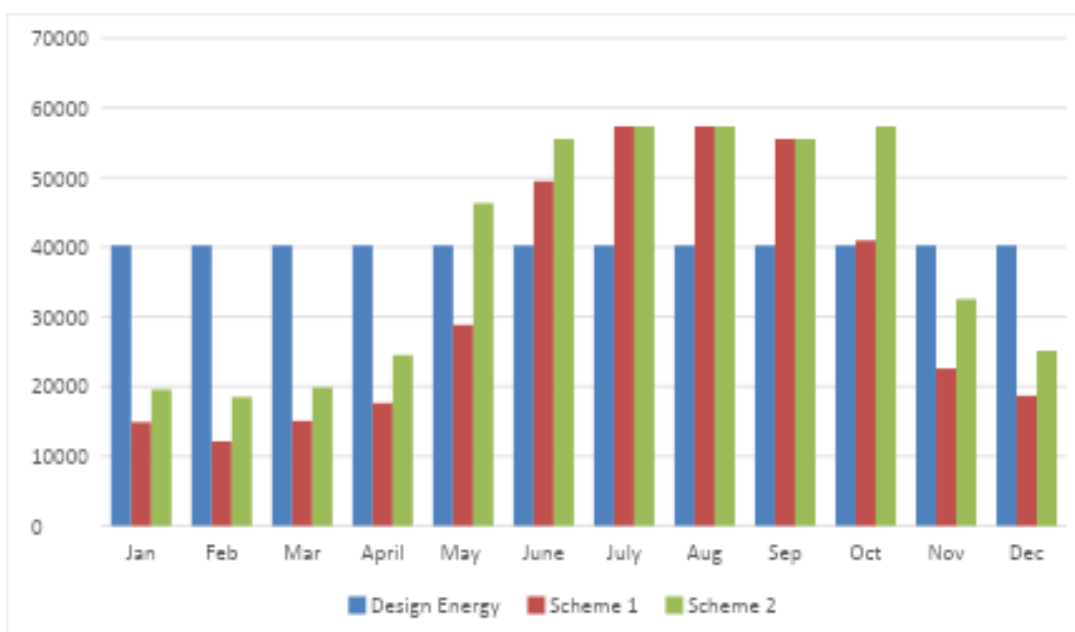


Figure 6: Energy comparison chart considering both flushing and turbine operation

C. Optimization of Peaking Hours

Results showed that downstream project's generation will be impacted under varying peaking time durations. The impact in generation of downstream project is simulated keeping all other assumptions constant and then, varying peaking hours of upstream project and downstream project from 1/2hrs to 3hrs (Table 2).

Table 2: Energy Generation at downstream project at different peaking hour

Energy of Downstream Project (Gwh)						
Peaking Hours of upstream project (Hr)	Peaking Hours of Downstream project (Hr)					
	1/2	1	1.5	2	2.5	3
1/2	472.48	476.83	481.17	485.51	489.85	494.20
1	472.34	476.75	481.15	485.56	489.96	494.37
1.5	472.20	476.67	481.18	485.61	490.00	494.55
2	472.00	476.59	481.13	485.67	490.20	494.75
2.5	471.85	476.51	481.12	485.73	490.34	494.95
3	471.74	476.42	481.11	485.80	490.49	495.18

Downstream project produces the least energy during 3hr peaking of the upstream project, when the peaking hours of downstream project is taken as 1/2hr, 1hr, and 1.5 hr. But when the peaking hour is taken as 2hr and more than 2hr (i.e. peaking hour of

downstream project ≥ 2 hr) for downstream project the generation of downstream project kept increasing even when peaking hour of upstream project is increasing.

4. DISCUSSION

It is seen that most of the projects reports and reviews were generally focused on the performance of sole project. While in reality multiple projects share same water resources and hydrological properties in single basin. Hence it is important to study how corresponding projects responds (A. Shrestha, 2023). Similar study has been carried out by Shah (2024) in Trishuli river basin by Shah (2024), projecting up to 6% generation loss in downstream project. This slight difference is because the impact depends on the project specific design, basin characteristics, and location. During upstream operation, the downstream project stores water for its own peaking needs, producing full energy during upstream peaking hours and spilling any excess discharge. However, during off-peak hours there is no water release, resulting to the substantial energy loss at downstream project.

5. RECOMMENDATION

A. Plan and Policy

To accommodate higher design discharge in the upstream project, a mutual understanding (through different framework like Memorandum of Understanding) must be established between upstream and downstream projects, to compensate for the energy loss at downstream project. Not only project to project coordination, governmental agencies like Department of Electricity Development should play an effective role during project siting, sizing, and operation. There should be the government policy on responsibility to borne the generation loss of downstream project caused by the upstream project to avoid the potential conflicts which may arise in the future between the developers of upstream and downstream project.

B. Research

Further study can incorporate hydraulic analysis for evaluating the impact of flow under tripping of upstream project. Also, incorporating hydrological model for hourly flow variation would be useful to prepare operational guide for the downstream project. This study can be further extended to financial modeling to translate the loss and gain in monetary terms and determine scale of financial vulnerability due to energy impact. Basin scale study combining multiple projects can facilitate the optimum water resources management. Understanding impact of climate change like alteration in magnitude of low and high flows can guide informed decision making in the highly vulnerable basins of Himalayas.

6. CONCLUSIONS

This study employed an integrated impact modeling framework to understand the linkage of upstream and downstream PRoR HPPs in the West Seti river basin. Following conclusions can be made from our analysis:

- i. Operational Scheme 2 is superior to scheme 1 for every combination. The loss in generation of downstream project is minimum for every combination when upstream project is running under scheme 2.
- ii. Continuous release of discharge with minimum turbine operation will give a better operation result for the downstream PRoR project i.e. Seti Nadi-3 HPP.
- iii. During the flushing of the upstream project the generation of the downstream project will be severely affected.
- iv. For optimal energy generation, minimum 2hr peak duration is best suited for downstream project.

The approach of this study is generalizable and can be propagated to develop basin scale insight on optimum multi-project combination. Our finding highlights the importance of evaluating downstream linkages for optimized design and operation of hydropower projects in the Himalayan basin.

SUPPLEMENTARY INFORMATION

None.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

- DoED. (2025). Retrieved from Department of Electricity Development.
- Asegdew G. Mulat, S. A. (April 2014). *Journal of Water Resource and Protection 2014*.
- Bhetuwa, M. P. (August 26, 2020). *HYDROPOWER DEVELOPMENT TRENDS AND*.

- Bibek Acharya, B. J. (December, 2020). Flood frequency analysis for an ungauged Himalayan river basin using different methods: a case study of Modi Khola, Parbat, Nepal. *Meteorology hydrology and Water Management*.
- Buddha Subedi, P. C. (2023). Comparative Study of Flood and Long-term Mean. <https://www.ngssnepal.org/journal>.
- CENTRE, A. H. (2008). HYDROPOWER ENGINEERING for Diploma Level Courses . ROORKEE : INDIAN INSTITUTE OF TECHNOLOGY, ROORKEE .
- Chilime Engineering & Services Co. Ltd.(CHESCO). (n.d.). *Status of The Study Seti Nadi -3 Hydropower Project*.
- Chilime Engineering & Services Co.Ltd. (2020). *Detail Project Report*. Nepal Electricity Authority.
- Claudia Kuenzer, I. C. (15 November 2012). Understanding the impact of hydropower developments in the context of upstream–downstream relations in the Mekong river basin. *Sustainability Science*.
- Department of Electricity Development. (2022, October 20). <http://doed.gov.np>. Retrieved from <http://doed.gov.np>: <http://doed.gov.np/license>
- Digna, R. F. (25 February 2021). Optimizing the Operation of a Multiple Reservoir System in the Eastern Nile Basin Considering Water and Sediment Fluxes. *Taylor & Francis Group an informa business*.
- Google earth pro. (2025). Retrieved from <https://earth.google.com/>: <https://earth.google.com/intl/earth>
- International Hydropower Association. (2022). Retrieved from <https://www.hydropower.org/>: <https://www.hydropower.org/iha/discover-types-of-hydropower>
- Khabar, U. (13 September, 2024). Types of Hydropower and their Structural Development. *Urja Gyan*.
- NEA. (2021). *Nepal Electricity Authority A Review in Fiscal year 2020/2021*. Nepal Electricity Authority .
- NEA. (2024). *Nepal Electricity Authority A year in Review Fiscal year 2023/2024*. Nepal Electricity Authority.
- Shah, P. (2024). Impact Study of Upstream Hydropower Projects on their Downstream Counterparts: A Case Study of Trishuli River Basin. *M.Sc. Thesis*. Tribhuvan University Institute of Engineering.
- Shuai Feng, Y. Z. (August 2022). Optimal operation of cascade hydropower station based on interior point method. *The 2nd International Conference on Power Engineering (ICPE 2021), December 09–11, 2021*. Nanning, Guangxi, China: Energy Reports.
- Sushrut Patki, R. M. (2023-03-13). A Hydroelectric Plant's Performance Evolution. *Ijraset Journal For Research in Applied Science and Engineering Technology*.