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Application of hydro-economic modelling for water resource management in the Kamala River Basin, Nepal

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Abstract: The Kamala River Basin spans approximately 2,084 km² across Nepal's Mahabharat Range, Chure Hills, and Terai Plains, flowing into India. Irrigated agriculture dominates water use, accounting for nearly 90% of total withdrawals, highlighting the critical role of water allocation in supporting rural livelihoods. Stakeholders seek strategies that enhance agricultural productivity and efficiency, hydropower generation, and environmental sustainability, while addressing increasing water deficit and socio-economic constraints.

This study integrates a Hydro-Economic Model (HEM) with an Cost-Benefit Analysis (CBA) to evaluate the feasibility, risks, and trade-offs of alternative Water Resources Development (WRD) options under six socio-economic scenarios representing alternative futures: Baseline (BL), Business-as-Usual (S1), Commercial Smallholder Agriculture (S2), Agribusiness (S3), Stagnant Agriculture (S4), and Unconstrained Agribusiness (S5). Four major WRD interventions were analysed:

- KIPR: Rehabilitation of the existing Kamala Irrigation Project
- GW: Sustainable groundwater development
- SS: Construction of small/medium upstream storages
- DS: Sunkoshi–Kamala inter-basin water transfer scheme in the lower basin

The HEM employs a node-link optimization framework to allocate water, determine cropping patterns and water requirements, and schedule hydropower production while satisfying physical, social, and ecological constraints. The model objective maximizes net economic benefits from irrigated agriculture and energy generation. Constraints include water balance, land limits, minimum ecological flow requirements, and institutional delivery rules. The model considers subsequent CBA incorporating infrastructure costs, benefit streams, and discount rates (6–9%).

The study results show that:

- Infrastructure and Agricultural Productivity: Combining KIPR with DS (the Sunkoshi–Kamala diversion) significantly improves water security under all scenarios. This enables irrigation expansion by 175,000 ha and under scenario S5 (intensified farming systems) leads to a tenfold increase in agricultural income.
- Scenario Feasibility: Scenarios BL, S1, and S4 remain economically unviable (benefit to cost ratio < 1.0). In contrast, S2, S3, and especially S5—which assumes no labour or input constraints—yield high returns, with IRR = 11.15% and resilience to a 79% increase in costs or 41.3% benefit reduction at a 6% discount rate.
- Scale of Interventions: Small-scale measures (GW, SS) deliver modest gains but are cost-effective (benefit to cost ratio = 1.77 under S5). Large-scale integrated schemes (KIPR + DS + GW + SS) maximize benefits despite high upfront costs by enabling year-round irrigation and hydropower production.
- Environmental Trade-offs: Allocating 10–20% of average monthly flows for ecological purposes has minimal economic impact (≤6.6% reduction in total benefits for small schemes; only 0.05% for large, combined schemes under S5), illustrating flexibility in balancing ecological sustainability with economic objectives.

Achieving economic viability (IRR ≥ 9%) for major infrastructure investments requires parallel improvements in agricultural productivity, including adoption of advanced farming practices, intensification, and strict cost discipline. The integrated HEM–CBA approach offers a robust decision-support framework to evaluate infrastructure portfolios, ecological trade-offs, and policy interventions in climate-vulnerable, smallholder-dominated landscapes. This approach demonstrates the potential to align water resource planning with agricultural modernization and provides actionable insights for resilient and inclusive basin-scale development strategies in Nepal and similar contexts.

Keywords: *Hydro-economic model; cost benefit analysis; water resources management; Kamala River Basin development; agricultural scenarios.*

