Assessing the Status and Policy Framework of Hydropower Projects in the Yamuna Basin, Uttarakhand: Implications for Sustainability and Local Communities

Sudheer Kumar* • Bhawna Siwach • Mahaveer Singh Negi

Department of Geography, School of Earth Science, H.N.B. Garhwal University, Srinagar, Uttarakhand-246174

*Corresponding Author Email Id: in.kumarsudheer@gmail.com

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Abstract: The Yamuna Basin, integral to the Ganga Basin, possesses significant hydropower potential due to its extensive river system and pronounced elevation gradient. This paper scrutinises the multifaceted impacts (environmental, social, economic) of hydropower development therein. Applying the DPSIR framework to the Lakhwar and Vyasi projects, the study identifies energy demand and water security as principal drivers, exerting pressures such as forest land diversion, hydrological alterations, and waste generation. Consequent state changes include habitat loss and transformation from lotic to lentic ecosystems, with impacts manifesting as biodiversity decline, disrupted fish migration, and the displacement of 1809 families. Institutional responses encompass resettlement packages, compensatory afforestation, and environmental management plans. The research also examines governance mechanisms and stakeholder roles, advocating for an integrated strategy that balances energy generation with ecological conservation by minimising disruption, considering cumulative effects, and strengthening regulatory oversight and social responsibility. This work contributes to the discourse on sustainable hydropower within Himalayanriver systems, focusing on the Yamuna Basin's distinct environmental and socio-economic context.

Keywords: Hydropower projects • Yamuna basin • Environmental impacts • Energy generation.

Introduction

The Himalayan region, often called the "Water Towers of Asia," is crucial in providing water and energy resources to a significant portion of the world's population (Immerzeel et al 2010). The region has immense potential for hydropower development, stemming from its steep topography and abundant rivers. This potential is increasingly recognised as a key strategy for meeting growing energy demands and promoting economic growth (Zarfl et al 2015). However, this pursuit of hydropower is not without complexities and challenges. Environmental and social impacts of dam construction are major concerns, sparking debates and, in some cases, significant resistance (Huber & Joshi 2015). Developing hydropower projects can lead to considerable alterations in river ecosystems, affecting water quality, sediment transport, and aquatic life (Kumar & Katoch 2016). Furthermore, dam construction often necessitates the displacement of communities and the loss of livelihoods, creating complex socio-economic challenges (Gyawali 2019). The Himalayan region's unique social, cultural, and ecological context requires careful consideration of these impacts. Specifically, planned projects in the Indian Himalayan Region require mandatory advice from the Central Electricity Authority (CEA) and environmental impact assessments (Agarwal & Kansal 2017).

Increasing energy demand and a global push towards renewable sources have intensified the focus on hydropower in the Himalayas (Binama et al 2017). This rapid expansion of hydropower projects raises concerns about their cumulative impacts on fragile mountain ecosystems and vulnerable communities (Lata et al 2017). High seismicity and susceptibility to natural hazards, such as landslides and floods, further complicate the situation, making risk assessment and management critical yet often overlooked aspects of hydropower development (Shaktawat & Vadhera 2020). A cost-benefit analysis, including a comprehensive methodology, helps address potential problems of implementing hydropower projects (Yildiz & Vrugt 2019). Framing hydropower as "green" energy emphasises its renewable nature but often obscures its development's complex trade-offs and potential negative consequences (Ahlers et al 2015). This framing can prioritise energy production over other crucial considerations, such as social equity and environmental sustainability. Integrating local communities, including their opinions about environmental hazards, into decision-making and project planning remains a key issue (Diduck et al 2013). Impacts are not limited to large dams; run-of-the-river projects also significantly affect downstream communities and river water quality (Rana et al 2007). Interaction between local communities, power dynamics, and decision-making processes will define how the hydropower sector responds to environmental and social impact challenges (Shome & Roy 2015). While projects may positively impact society, balancing those benefits with the potential drawbacks is crucial (Negi & Punetha 2017). The geographical dispersion of the impacts and benefits along the river should be considered. These include the upstream, at the project site, and downstream impacts and advantages (Huber, 2019). Moreover, the complexity of the projects will be enhanced if the project is built in a transboundary river. In that case, the countries involved must include factors considering the impact on social life and environmental conditions (Amjath-Babu et al 2019). This study employs the DPSIR (Driving Forces–Pressures–State–Impacts–Responses) framework, developed by the European Environment Agency (EEA 1999), to analyse hydropower development's environmental and socio-economic complexities in the Yamuna Basin. This model systematically examines the causal chain from anthropogenic drivers (e.g., energy demand, water security) and resultant pressures (e.g., land acquisition, ecological transformation, socio-economic displacement) to environmental changes and institutional responses (e.g., resettlement plans, ecological restoration). The purpose of the present study is to explore the status of hydropower projects in the Yamuna basin, which includes details of the various projects in different stages. As well as policy analysis on developing new hydropower projects at the state and central government levels.

Materials and Methods

Study Area: *Yamuna River basin*

The Yamuna basin is geographically situated between the coordinates 77.68°E, 30.42°N and 78.62°E, 31.29°N, encompassing the majority of the Uttarkashi district as well as portions of the Dehradun and Tehri districts. This basin features both the Yamuna and Tons rivers. The Yamuna River originates from the Bandarpunchh glacier, which converges with its tributaries—the Tons and Rupin rivers. Additionally, the Supin River, which originates from Har Ki Doon contributes to the basin's hydrology. Notably, the Tons River exhibits a greater flow rate than the Yamuna River (Fig 1). The total area of the basin is approximately 4,757 square kilometers, and its population is predominantly dispersed across a hilly landscape characterised by significant variations in altitude.

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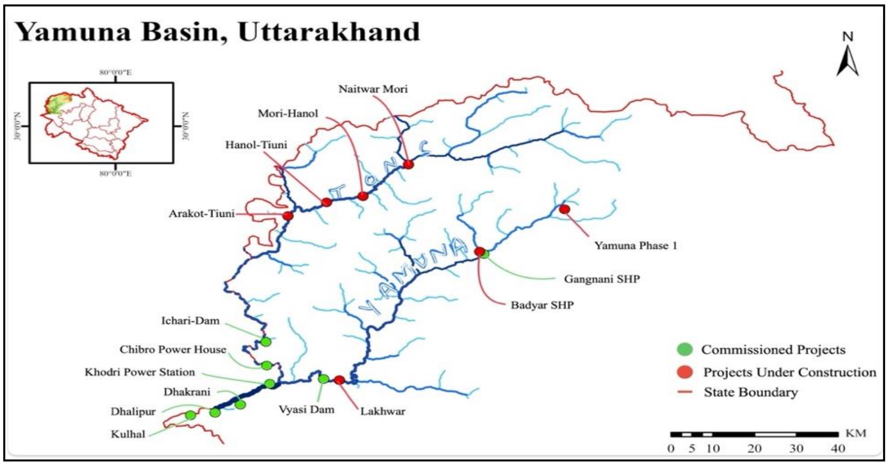

Fig.1. Yamuna Basin (commissioned and projects under construction) Source: UJVLN

Data collection: This study explores the current status of Hydropower projects in the Yamuna Basin. Which includes working, under construction and proposed projects. Policy analysis is also a key part of the current study. The data used is both primary and secondary, as well as field observations and interviews of dam authorities. Data on different projects was collected from various departments, and an extensive literature review was conducted. The data includes different EIA Reports, govt policy documents, news articles and academic papers.

DPSIR Framework: This study utilises the focus-based DPSIR (Driving Forces–Pressures–State–Impacts–Responses) framework to systematically evaluate the environmental and socio-economic implications of the Lakhwar Multi-Purpose Project (MPP) in the Yamuna Basin. It analyses driving forces such as energy demand and water security, along with land use change pressures, resource extraction, and hydrological alteration. The current state of the environment is assessed using indicators of ecological integrity and water quality. The resulting environmental and social impacts are identified, including habitat loss and community displacement. Finally, institutional responses, including mitigation strategies, policy instruments, and adaptive management plans, are critically examined to evaluate their effectiveness in promoting sustainable hydropower development.

Results and Discussion

Uttarakhand's Hydropower Landscape: As of March 31, 2024, the state of Uttarakhand in India had a total installed hydropower capacity of **4,254.17 MW**. This capacity is divided between small hydropower projects (SHPs), contributing **218.82 MW**, and large hydropower projects, which account for the majority at **4,035.35 MW.** Uttarakhand holds a significant position in India's hydropower sector, with an estimated considerable **hydropower potential of 13,481.35 MW**, constituting **10.11%** of the national capacity (**Fig 2**).

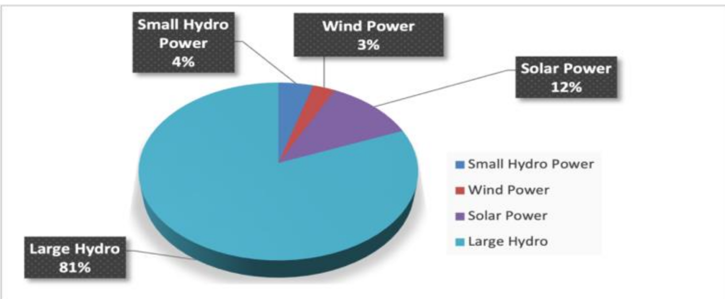

Fig. 2. Share of hydropower in renewable energy in Uttarakhand. Source: MNRE

Additionally, the state possesses **1,664.31 MW of small hydropower potential**, accounting for **7.88%** of India's total in this category. (MNRE Annual Report 2024). The state's Complex topography, characterised by mountainous terrain and perennial river systems, provides optimal conditions for hydroelectric development, reinforcing its role in the country's renewable energy transition (**Fig 3**).

National Energy Capacity and Growth Trends

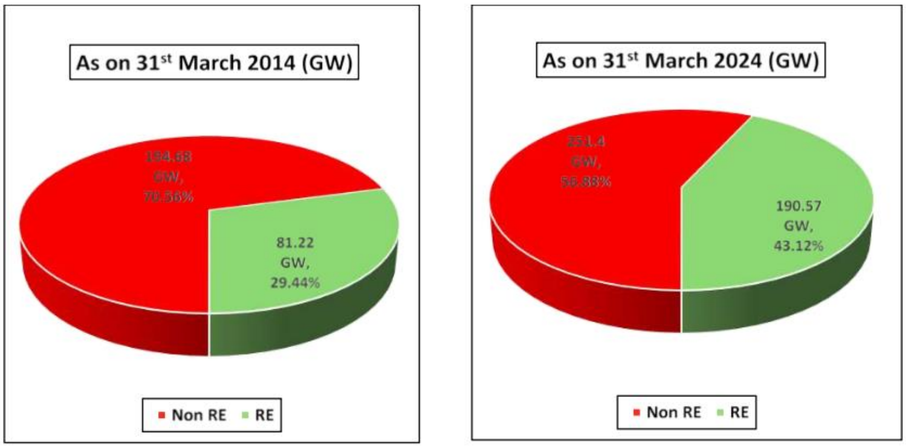

Fig. 3. Share of Renewable Energy Source: MNRE Annual Report 2023-24

India's Energy Sector Growth and Accelerated Renewable Transition: India's total installed power capacity reached 441.97 GW by March 2024, a 60.19% increase from 275.90 GW in 2014-15, driven by efforts to meet rising demand and enhance energy security. Concurrently, renewable energy (RE) capacity, including large hydropower, surged by 134.63% from 81.22 GW (2014-15) to 190.57 GW (2023-24) (MNRE, 2023-24). This commitment to cleaner energy is evidenced by 2023-24 RE capacity additions (18.56 GW) substantially outpacing non-renewable additions (7.35 GW). Since 2017-18, RE annual growth has consistently surpassed 6%, while non-renewable growth remained below 3.01%, underscoring a strategic national pivot towards sustainable energy sources.

Fig. 4. (A). Vyasi Dam, 86m Concrete Gravity Dam, FRL 631.5m (120 MW 60*2MW)
(B) Lohari village submerged in April 2023 Source: UJVNL, SANDARP

Commissioned Projects (Table 1)

Vyasi

The Vyasi Hydroelectric Project (120 MW), a run-of-the-river scheme on the Yamuna in Uttarakhand, constitutes part of the larger 420 MW Lakhwar-Vyasi complex—the Yamuna's most substantial hydroelectric development. The Lakhwar-Vyasi project (75 km from

Dehradun), comprising the Lakhwar Dam (300 MW) and the Vyasi component (120 MW Hathyari Power House), aims to generate 927 MU annually and irrigate 40,000 hectares (estimated at Rs. 1446.0 crores in 1996, with Rs. 227 crores then expended). The Vyasi project itself, designed for 375.22 MU annual generation through its dam, intake, tunnels, and powerhouse, has necessitated the submergence of six villages, displacing 334 families. Notably, the complete submergence of Lohari village (April 2023), home to Indigenous communities, incited protests over insufficient compensation (**Fig 4)**.

Ichari Dam

The Ichari Dam is a key part of the Yamuna Hydro-electric Scheme Stage II, about 80 km from Dehradun on the Tons River. It features a live storage capacity of 3.159 million cubic meters, a crest elevation of 652.0 meters, and a spillway with seven bays capable of discharging 13,500 cubic meters per second. The dam diverts water into a 6.2 km power tunnel that supplies the underground Chibro Powerhouse, housing four 60 MW units. The outflow can either flow into the Tons River or enter the second part of the scheme. The Khodri Power Plant, located upstream of the Dakpathar Barrage, utilises discharge from Chibro with a hydraulic head of 62 meters through a 5.6 km tunnel, supporting four 30 MW units and generating 450 million units annually (**Fig 5)**.

Fig. 5. Ichari Dam 60m Concrete Gravity Dam. FRL - 644m
Chibro-60*4mw and khodri-30*4mw Source: UJVNL, field survey

Notably, both powerhouses operate in tandem, a first of its kind globally, with operational challenges successfully managed.

Table 1. Commissioned Projects in the Yamuna Basin

S. No.	**Name of HEP**	**District**	**River and Tributary**	**River/ Gad Name**	**Name of Developer**
1	Istar gad (0.20MW)	Dehradun	Tons		UJVNL
2	Khodri (120MW)	Dehradun	Tons		UJVNL
3	Chibro (240MW)	Uttarkashi	Tons	Istar Ganga	UREDA
4	Kulhal (30MW)	Uttarkashi	Yamuna		UREDA
5	Hanuman Ganga (4.95MW)	Dehradun	Yamuna		UJVNL
6	Dhalipur (51MW)	Dehradun	Yamuna		UJVNL
7	JankiChatti (0.20MW)	Dehradun	Yamuna		UJVNL
8	Galogi (3MW)	Dehradun	Yamuna	Asan/Kiyarkuli	UJVNL
9	Dhakrani (33.75MW)	Uttarkashi	Yamuna	Hanuman Ganga	REY

Projects Under Construction (Table 2)

Lakhwar Multipurpose Project (300 MW)

The Lakhwar Multipurpose Project on the Yamuna River in Uttarakhand, India, is a 300 MW hydroelectric power initiative by UJVN Ltd. It features a 204m concrete gravity dam with an underground powerhouse, housing three 100 MW vertical Francis turbines. The reservoir has a full reservoir level (FRL) of 796 meters and a minimum drawdown level (MDDL) of 752 meters, with a gross storage capacity of 587.84 MCM, allowing for diurnal peaking operations.

The project entails acquiring 927.0822 hectares of land, including 158.927 hectares of private land and 768.1552 hectares of forest land. While forest land diversion is complete, 53.505 hectares of private land remain to be acquired, affecting approximately 650 families. Overall, 1,831 families in 35 villages have been identified as project-affected, with compensation provided to 1,181 families.

Table 2. Projects Under Construction

S. No.	Name of HEP	District	River and Tributary	River/ Gad Name	Name of Developer
1.	Kishau	Uttarkashi	Tons		UJVNL
2.	Badiyar (4.9MW)	Uttarkashi	Yamuna	Badiyar gad	REY
3.	Rayat (3MW)	Tehri	Yamuna	Aglar	Aglar Power
4.	Langrasu (3MW)	Tehri	Yamuna	Aglar	Aglar Power
5.	Lakhwar (300MW)	Dehradun	Yamuna		UJVNL

Kishau Dam Project (660 MW)

The Kishau Dam Project, a proposed 660 MW hydroelectric project, is planned for the Tons River. The project site was relocated to Sambarlekha (Uttarakhand) and Maina Vaas (Himachal Pradesh), 15 km from the village of Kishau, due to the initial site's unsuitability (**Fig 6**).

Name of Project	*Capacity (MW)*	*District*	*River*	*Name of Project*	*Capacity (MW)*	*District*	*River*
Deora-Mori	(27MW)	Uttarkashi	Tons	Hanuman-Chatti	(40MW)	Uttarkashi	Yamuna
Mori-Hanol	(27 MW)	Uttarkashi	Tons	Saina-Chatti-Kuthnaur	(12MW)	Uttarkashi	Yamuna
Hanuman-Chatti	(33 MW)	Uttarkashi	Yamuna	Sauli–Barnigad	(10MW)	Uttarkashi	Yamuna
Barnigad-Naiangaon	(34 MW)	Dehradun	Yamuna	Barnigad	(6.50MW)	Uttarkashi	Yamuna
Taluka-Sankri	(140MW)	Uttarkashi	Tons	Pali-gad	(0.30MW)	Uttarkashi	Yamuna
Sidri-Deori	(60MW)	Uttarkashi	Tons	Riknal-Khad	(4MW)	Dehradun	Yamuna
Mori-Hanol	(63MW)	Uttarkashi	Tons	Garsad-Khad	(4.50MW)	Dehradun	Yamuna
Hanol-Tiuni	(60MW)	Dehradun	Tons	Thatyur	(4MW)	Tehri	Yamuna
Tuini-Plasu	(66MW)	Dehradun	Tons	Ringali	(1MW)	Tehri	Yamuna
Jakhol-Sankri	(35MW)	Uttarkashi	Tons	Purkul	(1MW)	Dehradun	Yamuna
Arakot-Tuini	(70MW)	Uttarkashi	Tons	Tewa	(3.50MW)	Tehri	Yamuna
Rupin-II	(10MW)	Uttarkashi	Tons	Bangseel	(3.50MW)	Tehri	Yamuna
Rupin–III	(3MW)	Uttarkashi	Tons	Asnor-gad	(0.50MW)	Uttarkashi	Yamuna
Rupin–IV	(10MW)	Uttarkashi	Tons	Bhadri-gad	(24MW)	Tehri	Yamuna

For dam construction. The project's extensive footprint spans three districts across the two states. The dam site is located 70 km from Dehradun, accessible via the road to Tiyuni town, which marks the zero point of the dam's backwaters. Nine villages in Uttarakhand and eight in Himachal Pradesh (six in Sirmour district and two in Shimla district) will be affected by the Kishau Dam project. 2950 hectares of area will be submerged, comprising 512 ha of cultivated private land and 2438 ha of forest land. A total of 701 families will be affected by the project.

Fig. 6. Site of Kishau Dam (under construction) Source: UJVNL

Proposed Projects (Table 3)

Nearly 40 projects of 1400 MW are proposed in the basin of different sizes; most of which are small hydropower projects. These projects are built on small tributaries (Gad) of Yamuna. Its size varies from 0.5 MW to 140 megawatts. Below is a list of these projects. (Table:1)

Hydroelectric Development Policies

Micro & Mini Hydro Power Projects Development Policy up to 2 MW (2015)

Despite Uttarakhand's hydropower potential of approximately 3000 MW, only ~170 MW is currently utilised via small projects. A comprehensive policy is imperative to promote micro and mini hydropower, targeting socioeconomic development, enhanced rural electrification, and decentralised energy solutions for agriculture, industry, and households; project eligibility is restricted to local Gram Panchayats (prioritising the powerhouse location). The Uttarakhand Renewable Energy Development Agency (UREDA) has commissioned 44 micro hydropower projects (4.29 MW total), electrifying over 300 villages and hamlets.

Improved Watermill Programme

Uttarakhand has approximately 15,449 traditional watermills (Gharats), either operational or defunct. Upgraded watermills can generate up to 5 kW of power, sufficient to electrify 15–20 households within a 500-meter radius. To support their modernisation, the State Government provides a subsidy of ₹6,000 per watermill in addition to the Ministry of New and Renewable Energy (MNRE) subsidy, which includes ₹1.10 lakh for electrical/electromechanical upgrades and ₹35,000 for mechanical improvements. By 2013, 1,341 watermills had been upgraded, including 298 in the Chamoli district.

Ultra-low head micro-hydro projects (UNIDO)

UNIDO offers an innovative solution for electricity generation at ultra-low head levels (below 3.0 meters) with a discharge range of 0.8–3.0 m^3/s. The initiative aims to establish a favourable environment for the deployment of local technology.

Small Hydropower Projects above 2 MW and Up to 25 MW

For small hydropower projects ranging from 2 MW to 25 MW, the Uttarakhand State Government plans to invite open bids for development under the Public-Private Partnership (PPP) model. These projects will only be allocated after a detailed project report by the state government agencies is prepared. They can be developed as Independent Power Plants (IPPs) or Captive Power Plants (CPPs). They are categorised based on capacity into

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two groups: small hydropower projects above 2 MW, up to 5 MW, and those above 5 MW.

Policy on hydropower development by the private sector in the state of Uttarakhand (25 MW to 100 MW)

The hydropower development policy in Uttarakhand allows private sector participation for projects with capacities between 25 MW and 100 MW, effective from the publication date. Eligible projects include those with an installed capacity of 25 MW or more, and bids are invited from qualified entities such as private firms and joint ventures. Uttarakhand Jal Vidyut Nigam Ltd. (UJVNL) will conduct pre-feasibility studies and address evacuation needs. The policy governs projects exceeding 100 MW throughout their duration, with the Government of Uttarakhand inviting investments and providing preliminary profiles before bidding.

DPSIR farmwork analysis of Lakhwar MPP

Driving Forces

The impetus for the Lakhwar Multipurpose Project stems from several critical socio-economic and developmental drivers. A primary driving force is the escalating regional and national demand for electrical energy, particularly for reliable peaking power, coupled with a strategic objective to augment the share of renewable energy in the national grid. Concurrently, the project addresses pressing water security concerns by enhancing irrigation capabilities and ensuring a sustained drinking water supply for six beneficiary states. Beyond these direct outputs, project proponents anticipate that the LMPP will catalyse broader regional economic development, offer flood control benefits, and contribute to the ecological rejuvenation of the Yamuna River, thereby aligning with multifaceted national development goals (**Fig 7**).

Pressures on the Environment

Operationally, the most significant pressure from the Lakhwar dam will be the creation of a 9.57 sq km reservoir, leading to the submergence of 23 km of the Yamuna River and 5 km of the Aglar River. This will fundamentally alter the existing flowing water ecosystem to a still water environment. The Vyasi HEP, situated 5 km downstream, already exerts its own set of pressures through its existing/forming reservoir and operational regime, which will now directly interact with and be influenced by the regulated releases from the Lakhwar dam. The minimal 100-meter stretch between the Lakhwar Tail Race Tunnel outlet and the Vyasi FRL underscores this direct hydrological linkage. Furthermore, the village of Lohari, which was submerged in April 2023, affected 77 families, highlighting the significant social impact of these hydrological changes.

State of the Environment

The baseline environmental assessment indicates good air quality (CPCB compliant), though National Highway 507 traffic elevates noise. Yamuna and Aglar river surface waters are typically 'Class B,' with potable groundwater; the Yamuna's Water Quality Index ranges from "Good" (pre-monsoon) to "Medium" (monsoon). The predominantly forested region (>52%, with ~27% agriculture) features moderately fertile, low-potassium Brown Forest soils. It supports diverse flora (324 species) and typical Himalayan foothill fauna, including Rhesus macaque, Common langur, and the Near Threatened Himalayan Griffon. Lakhwar dam will permanently modify Yamuna's flow, create a large reservoir, and result in the loss of ~768 hectares of forest and riverine habitat, consequently altering aquatic ecology and impeding fish migration, with the Vyasi project initiating similar proximate effects.

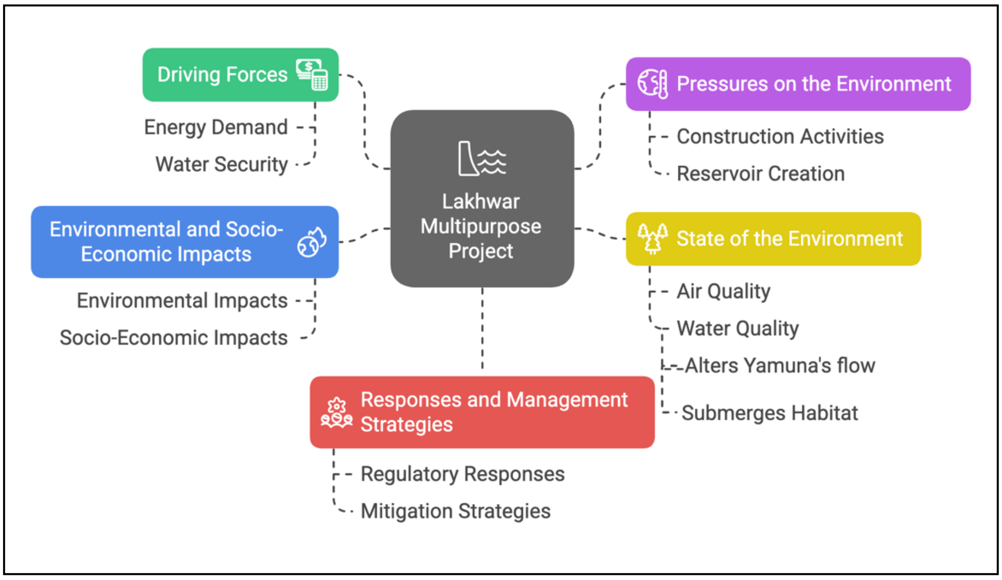

Fig.7. DPSIR Framework for Lakhwar Multipurpose Project

Environmental and Socio-Economic Impacts (DPSIR Framework)

The modified Lakhwar project is expected to have significant environmental impacts, including the irreversible loss of the riverine ecosystem and blocked migratory paths for key fish species like Mahseer and Snow Trout. If not adequately managed, construction may lead to air and water quality issues from dust and runoff. Socially, the project will affect 1,809 families by acquiring land and disrupting agriculture and traditional livelihoods. Additionally, an influx of construction workers could strain local infrastructure, causing social tensions and health risks. On the positive side, the project offers job creation and economic benefits, supported by a Rs. 28.75 crore Local Area Development plan and a Rs. 234.085 crore rehabilitation package for infrastructure and skill development. A comprehensive Disaster Management Plan has been created to address potential dam failure risks, identifying 47 vulnerable downstream villages. The more advanced Vyasi Hydroelectric Project will help mitigate immediate downstream impacts for Lakhwar.

Responses and Management Strategies (DPSIR Framework)

A comprehensive framework of responses, encompassing regulatory measures, mitigation strategies, and management plans, has been developed to address the identified impacts. Key regulatory responses include this EIA, the Environmental Clearance (EC) obtained for Lakhwar MPP in 2021, and the prior EC for Vyasi HEP (2007), alongside directives from the National Green Tribunal and clearances from the National Board for Wildlife, all of which were informed by public consultations (Table 4). The cornerstone of the response strategy is the Environmental Management Plan (EMP) for Lakhwar MPP, with a total outlay of Rs. 296.85 crore (excluding CAT plan costs). This EMP integrates several specific sub-plans.

Table 4. Environmental Management Plan (EMP) for Lakhwar MPP

Plan	Details	Budget (in Lakh Rs.)
Catchment Area Treatment (CAT) Plan	Addresses watershed stability	8586.25
Compensatory Afforestation	956.0 hectares afforested for Lakhwar-Vyasi project area	Not specified
Rehabilitation & Resettlement (R&R) Plan	For 1809 Project Affected Families as per Uttarakhand R&R Policy 2013	23408.5
Local Area Development (LAD) Plan	Improves infrastructure and socio-	2875.0

	economic conditions in affected villages	
Fisheries Management Plan	Fish hatcheries near Lohari and Chamiya villages, stocking programs	1351.44
Muck Management Plan	Scientific disposal and restoration of muck dumping sites (1987–92)	185.13
Green Belt Development Plan	Plantations along roads, around colonies, and the reservoir rim	103.48
Reservoir Rim Treatment Plan	Treating landslides and stabilizing slopes around reservoir	351.41
Disaster Management Plan	Preparedness for dam break and related emergencies	200.00
Environmental Monitoring Program	Ongoing monitoring of air, water, noise, and ecology	72.40

These responses aim to minimise adverse effects, compensate for unavoidable losses, and enhance positive outcomes, ensuring the project's progression in an environmentally and socially responsible manner. The operational integration between Lakhwar and Vyasi has been a key consideration in formulating these comprehensive management strategies.

Conclusion

Uttarakhand's Yamuna basin, a key hydropower hub (600 MW commissioned, >1200 MW under construction, ~1400 MW proposed), faces significant environmental and socioeconomic risks from this rapid development, impacting its fragile Himalayan ecosystem and vulnerable communities. While addressing energy and water needs, the Lakhwar Multipurpose Project (LMPP) exemplifies these challenges through riverine habitat loss, forest diversion, community displacement, and altered Yamuna flow/ecology. Mitigation demands a comprehensive Environmental Management Plan (afforestation, resettlement, biodiversity conservation). Balancing infrastructure with ecological sustainability and community welfare in this sensitive region necessitates rigorous monitoring and adaptive management.

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