Himalayan Dam Projects in India and Their Implications: A Deep Dive into the Dhauliganga Hydropower Initiative

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Abstract Indian Himalayan region represents a confluence of remarkable biodiversity that is challenged with developing sustainable hydropower infrastructure. The present study examines different dam projects across the Indian Himalaya, specifically focusing on the Dhauliganga Hydropower Initiatives. Our study first elucidates the threatened flora and endangered fauna that characterize this unique ecosystem, thus spanning the ecological wealth of the region. We then outline the current landscape of river basins housing major dams, encompassing regions including Jammu and Kashmir, Himachal Pradesh, Uttarakhand, and Northeastern India. Crucially, the impacts of these infrastructural projects present a two-fold challenge: environmentally, they disrupt local ecosystems, while socioeconomically, they induce displacement, affecting local communities. Our in-depth examination of the Dhauliganga Basin illustrates the intricate balance between harnessing energy and preserving

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ecology. Drawing from the diverse hydroelectric projects, forest types, and ecological vulnerabilities within the basin, we emphasize the need for a balanced approach. In conclusion, we advocate for holistic development strategies that prioritize sustainable energy harnessing and conservation. This research seeks to contribute insights that shape the course of future hydropower projects toward greater environmental and social sustainability.

1 Introduction

Extending across India, Bhutan, China, Nepal, and Pakistan, the Himalayan region is often recognized as the 'third pole,' encapsulating geological and cultural significance that stretches back approximately 40–50 million years (Harrison et al., 1992). This vast expanse originates from the subduction of the Indian plate beneath the Eurasian plate, not only highlighting the impressive power of nature but also giving rise to some of the world's most vital rivers, including the Indus, Ganges, and Tsangpo–Brahmaputra (Yin, 2006). The Himalaya provide a habitat for approximately 53 million people and profoundly influence the livelihoods of nearly 600 million individuals residing within its expansive drainage basin.

The Himalayas hold significant cultural value and potential for renewable energy generation through hydropower (Lewis, 1994). This potential can facilitate the worldwide shift towards cleaner energy, mitigate carbon emissions, strengthen energy security, and boost local economies. However, pursuing this potential also brings environmental and social concerns. The region's delicate ecosystem risks degradation and biodiversity loss from construction, while local communities face displacement. Altered river flows can disrupt downstream ecosystems, and exclusive dependence on hydroelectricity might limit energy source diversification. India has committed to enhancing its reliance on renewable energy to 40% by 2030, with hydroelectricity being a cornerstone of this strategy (TERI, 2021). However, climate change challenges, like glacier retreat and flood risks, complicate sustainable hydropower endeavors in the region.

Hydroelectric projects exhibit variability in terms of their design and environmental ramifications. Run-of-River (RoR) projects direct river water through turbines and back downstream without large reservoirs. This design generally causes minimal upstream disruption and lessens the risk of large-scale habitat fragmentation. However, they can still modify flow regimes and potentially impact aquatic life downstream (Fryirs, 2013). Reservoir Projects use dams to store water for controlled release, ensuring consistent electricity output. While ensuring energy stability, these reservoirs can lead to large-scale flooding, displacing local communities and wildlife and changing aquatic ecosystems (Zarfl et al., 2015). Pumped Storage Projects utilize two reservoirs at different elevations: during low demand, water is pumped upward using excess power, and during high demand, it is released downward through turbines to generate electricity. While they offer flexible energy storage and grid stabilization, they might lead to water loss due to evaporation, local temperature changes that affect aquatic life, and potential disruptions in both upstream and downstream ecosystems.

The significance of these dams is undeniable; from a global count of 5000 large dams in 1950, this number ballooned to 58,000 by September 2021 (Zarfl et al., 2015). The Himalayan river basins, especially the Ganga, Indus, and Brahmaputra, have become focal points for dam construction due to their immense hydropower potential (Hussain et al., 2019). However, with development comes challenges. The ecological implications of these dam constructions, especially within the unique ecosystem of the Himalaya, are concerning. With a diverse range of endemic and threatened flora and fauna, there is an increasing risk to the balance of these pristine ecosystems (Pandit et al., 2014). Despite India housing a significant portion of the world's population, there is a gap in understanding the cumulative ecological impacts of its aggressive dam-building endeavours.

Nestled amidst the captivating Himalayan landscape, the Dhauliganga River Basin uniquely positions itself as an integral sub-basin of the Alaknanda River Basin. It is emerging from glacial reserves and harmonizes with neighboring river basins by exhibiting shared high-altitude ecosystems. Yet, its distinct contribution to the Ganga Basin sets it markedly apart. In the Jammu and Kashmir region, it provides a gentle contrast to the expansive realms of the Indus, Chenab, and Ravi Basins, emphasizing its nuanced yet pivotal role in the larger Ganga watershed. Within Himachal Pradesh, the Dhauliganga weaves a different story from the heavily hydropower-centric narratives of the Sutlej and Beas Basins, focusing instead on its integral contribution to the Ganga's lifeblood. As it meanders through Arunachal Pradesh, it draws parallels with the glacial origins of the Brahmaputra and Lohit Basins, yet its impact remains uniquely localized. In Uttarakhand, the basin seamlessly integrates with the Alaknanda and Bhagirathi Basins, further emphasizing its crucial role in the Ganga River's formation. Amid the tapestry of India's myriad river basins, the Dhauliganga Basin etches its significance by threading together diverse ecosystems, potential for power generation, and deep-rooted cultural vistas.

The Dauliganga river boasts a steep gradient and substantial flow rates, making it a prime candidate for harnessing hydroelectric power. Numerous glacial lakes are forming in this region due to the temperature rise. Some of them may burst, i.e., Glacier Lake Outburst Flood (GLOF) may occur, causing loss of lives, properties, and infrastructures in downstream areas. In fact, several hydroelectric projects have also been proposed in this region. Comprehensive research can direct sustainable energy production, mitigating potential ecological disturbances. In light of the above, this study sets forth the following objectives: (i) Provide a thorough analysis of dam constructions in the Indian Himalayan ecosystem, examining their distribution, potential, and the ecological and socioeconomic consequences they entail; and (ii) Delve into the Dhauliganga basin of Uttarakhand, exploring both the challenges and opportunities linked to its hydroelectric development, while proposing strategies to balance energy goals with the preservation of its distinct ecological assets.

2 Indian Himalayan Region: An Insight into the Bounteous yet Endangered Biological Wealth

Spanning an expansive and ecologically varied area of approximately 530,000 km^2 and stretching across 2500 km, we encounter the Indian Himalayan Region (IHR). Despite encompassing just 13% of India's geographical landscape, the Indian Himalayan region (IHR) shelters nearly 50% of the country's documented biodiversity, a substantial portion of which is endemic to the IHR. Despite its relatively compact dimensions, the IHR boasts remarkable diversity in its physiography, geography, climate, and altitude, enriched by its abundantly diverse biota (IUCN Red List). Hence, the IHR offers a habitat for a multitude of biosphere reserves, national parks, and wildlife sanctuaries, providing a haven for exceptional and vulnerable species such as the snow leopard, red panda, and black-necked crane. The locality includes diverse ecosystems, spanning alpine meadows, temperate forests, and subtropical forests (Kumar & Pandit, 2018). The cultural diversity of the IHR is equally vibrant, interwoven with myriad indigenous communities, each contributing their unique languages, traditions, and festivals (Vedwan & Rhoades, 2001).

2.1 Threatened Flora of the Indian Himalayan Region

The breathtaking expanse of the Indian Himalayan region, often dubbed the "abode of snow", not only forms an imposing natural barrier but also serves as a melting pot of ecological diversity. Within this magnificent region, we find a plethora of unique plant species, each playing a pivotal role in its intricate ecosystem. Yet, a growing concern is the increasing number of these species that are now on the brink. Table 2 offers a comprehensive glimpse into the threatened flora across various states and territories in this region. The categorization—spanning from critically endangered (highlighted in red), endangered (deep yellow), vulnerable (light yellow), near-threatened (green), to rare (black)—is a stark reminder of the fragility of our natural heritage (Hilton-Taylor & Brackett, 2000) (Table 1).

In the picturesque valleys and lofty peaks of Jammu and Kashmir, we encounter species like the medicinal *Aconitum heterophyllum*, the beautiful *Lilium polyphyllum*, and the aromatic *Nardostachys jatamansi*, among others like *Aconitum violaceum*, *Angelica glayca*, *Gentiana kurroo*, *Lilium polyphyllum*, *Nardostachys jatamansi*, *Saussurea costus*, and *Ulmus wallichiana* (Table 1).

Himachal Pradesh, known for its verdant meadows and snow-capped mountains, houses gems like the vibrant Acer caesium, the rare *Erysimum thomsonii*, and the coveted *Saussurea costus*, a plant that holds both economic and medicinal significance. In Himachal Pradesh, the threatened flora list includes *Acer caesium*, *Allium stracheyi*, *Saussurea bracteata*, *Campanula wattiana*, *Silene kunawarensis*, *Carex munroi*, *Hedysarum microcaly*, *Eremurus himalaicus* among others.

Table 1 Details of threatened floral taxa of the Indian Himalayan region (CR-critically endangered, EN-VU-vulnerable, NT-near-threatened, and R-rare species)

Jammu and Kashmir	Himachal Pradesh	Uttarakhand	Sikkim, West Bengal, and Arunachal Pradesh
• Aconitum heterophyllum$_{NT}$	• Acer caesium$_{VU}$	• Acer caesium$_{VU}$	• Acer hookeri$_{NT}$
• Aconitum violaceum$_{VU}$	• Allium stracheyi$_{VU}$	• Acer oblongum$_{NT}$	• Pimpinella tongloensis$_{NT}$
• Angelica glayca$_{NT}$	• Saussurea bracteata$_{R}$	• Allium stracheyi$_{NT}$	• Pimpinella wallichii$_{NT}$
• Gentiana kurroo$_{CR}$	• Saussurea costus$_{NT}$	• Trachycarpus takii$_{R}$	• Calamus inermis$_{NT}$
• Lilium polyphyllum$_{CR}$	• Erysimum thomsonii$_{R}$	• Catamixis baccharoides$_{VU}$	• Phoenix rupicola$_{R}$
• Nardostachys jatamansi$_{CR}$	• Campanula wattiana$_{R}$	• Lactuca filicina$_{NT}$	• Ceropegia hookeri$_{NT}$
• Saussurea costus$_{CR}$	• Silene kunawarensis$_{R}$	• Saussurea costus$_{NT}$	• Lactuca cooperi$_{NT}$
• Ulmus wallichiana$_{VU}$	• Carex munroi$_{R}$	• Berberis lambertii$_{VU}$	• Begonia rubella$_{R}$
	• Hedysarum microcaly$_{NT}$	• Cyananthus integra$_{R}$	• Codonopsis affinis$_{R}$
	• Eremurus himalaicus$_{R}$	• Arenaria curvifolia$_{NT}$	• Dennstaedtia elwesii$_{R}$
		• Arenaria ferruginea$_{NT}$	• Juncus sikkimensis$_{R}$
		• Hedysarum microcalyx$_{VU}$	• Lagerstroemia minuticarpa$_{R}$
		• Aphyllorchis gollani$_{NT}$	• Coelogyne treutleri$_{R}$
		• Aphyllorchis parviflora$_{R}$	• Cymbidium eburneum$_{VU}$
		• Archineottia microglottis$_{R}$	• Cymbidium hookerianum$_{VU}$
		• Calanthe alphina$_{R}$	• Cymbidium whiteae$_{NT}$
		• Calanthe mannii$_{R}$	• Paphiopedilum fairrieanm$_{NT}$
		• Didiciea cunninghami$_{NT}$	• Cotoneaster simonsii$_{R}$
		• Diplomeris hirsuta$_{VU}$	• Cissus spectabilis$_{NT}$
		• Flickingeria hesperis$_{NT}$	• Acer osmastonii$_{NT}$

(continued)

Table 1 (continued)

Jammu and Kashmir	Himachal Pradesh	Uttarakhand	Sikkim, West Bengal, and Arunachal Pradesh
		• Cypripedium elegans$_{R}$	• Aneilema glanduliferum$_{VU}$
		• Christella kaumaunica$_{VU}$	• Cymbidium eburneum$_{VU}$

The rugged terrains of Uttarakhand, a land interspersed with sacred shrines, is home to species such as the towering *Trachycarpus takii*, the herbaceous *Allium stracheyi*, and the vibrant-hued *Berberis lambertii*. The other species of Uttarakhand include *Acer caesium*, *Acer oblongum*, *Catamixis baccharoides*, *Lactuca filicina*, *Saussurea costus,* etc..

Diving further east, the territories of Sikkim, West Bengal, and Arunachal Pradesh—regions drenched in monsoons and rich tribal cultures—harbor diverse species. Here, we find the resilient *Acer hookeri*, the delicate *Pimpinella wallichii*, and the rare *Phoenix rupicola* (Table 1). The threatened flora of the region also encompasses *Pimpinell atongloensis*, *Calamus inermis*, *Ceropegia hookeri*, *Lactuca cooperi*, *Begonia rubella*, and *Codonopsis affinis*. It is paramount to prioritize conservation efforts to protect these species, especially those categorized as critically endangered and endangered, to maintain the ecological balance and rich biodiversity of the Indian Himalayan region.

The threatened flora discussed above calls for intensified conservation efforts. It is imperative to harness both community involvement and scientific interventions to protect these species, especially the critically endangered and endangered ones. By doing so, we not only preserve the rich biodiversity of the Indian Himalayan region but also ensure the continued health of an ecosystem that countless communities and wildlife depend upon.

2.2 Endangered Fauna in the Indian Himalayan Region

The Indian Himalayan region, characterized by its immense biodiversity and various ecosystems, has long been recognized as a crucial habitat for various fauna species. However, the escalating threats, primarily due to human-induced activities, have rendered several species vulnerable to extinction. Table 3 provides a comprehensive view of this endangered fauna across different regions of the Indian Himalayan region.

Jammu and Kashmir is marked by species such as the Kashmir grey langur, Himalayan musk deer, and the Hangul, indicating this region's importance in faunal biodiversity. The other endangered species of the region include Sambar, Snow leopard, Urial, Kashmir musk deer, and Common leopard.

Table 2 Details of endangered faunal taxa in the Indian Himalayan region (CR-critically endangered, VU-vulnerable, NT-near-threatened and R-rare species)

Jammu andKashmir	Himachal Pradesh	Uttarakhand	Sikkim, West Bengal, and Arunachal Pradesh
• Kashmir grey langur$_{NT}$	• Tibetan wolf$_{NT}$	• Peter's tube-nosed bat$_{CR}$	• Tibetian Wolf$_{NT}$
• Himalayan musk deer$_{NT}$	• Himalayan serow$_{VU}$	• Fishing cat$_{VU}$	• Red Fox$_{R}$
• Kashmir musk deer$_{NT}$	• Bearded vulture$_{R}$	• Tiger$_{NT}$	• Tibetian fox$_{R}$
• Hangul$_{CR}$	• White-rumped vulture$_{CR}$	• Snow leopard$_{NT}$	• Red panda$_{NT}$
• Sambar$_{VU}$	• Slender-billed vulture$_{CR}$	• Sloth bear$_{VU}$	• Fishing Cat$_{VU}$
• Wild yak$_{VU}$	• Himalayan tahr$_{NT}$	• Indian elephant$_{NT}$	• Clouded Leopard$_{VU}$
• Urial$_{VU}$	• Himalayan musk deer$_{NT}$	• Pygmy hog$_{CR}$	• Leopard$_{VU}$
• Common leopard$_{VU}$	• Koklass pheasant$_{NT}$	• Swamp deer$_{VU}$	• Tiger $_{NT}$
• Snow leopard$_{VU}$	• Snow leopard$_{VU}$	• Himalayan tahr$_{VU}$	• Snow Leopard$_{VU}$
	• Red-headed vulture$_{CR}$	• Serow$_{VU}$	• Tibetian Wild Ass$_{NT}$
		• Himalayan monal$_{R}$	• Pygmy$_{CR}$
		• Bharal$_{R}$	• Musk Deer$_{NT}$
		• Himalayan Quail$_{CR}$	• Tibetian Gazelle$_{R}$
		• Oriental White-rumped Vulture$_{CR}$	• Serow$_{VU}$
		• Slender-billed Vulture$_{CR}$	• Himalayan Tahr$_{NT}$
		• King Vulture$_{CR}$	• Bharal$_{R}$
		• Baer's Pochard$_{CR}$	• Great Tibetian sheep$_{R}$
		• Egyptian Vulture$_{NT}$	• Crestless Porcupine$_{R}$
		• Black-bellied Tern$_{NT}$	• Asian elephant$_{NT}$
		• Cheer Pheasant$_{VU}$	• Barking deer$_{R}$
		• Long-tailed Duck$_{VU}$	• Bengal florican$_{CR}$
		• Saras Crane$_{VU}$	• Black-necked crane$_{R}$
			• Great one-horned rhino$_{VU}$

Table 3 Overview of the large dams (10–15 m in height with a storage capacity of over 60 million cubic meters) situated throughout the Indian Himalayan region

Dam	River	District	Power output (MW)	Year
Jammu and Kashmir				
Bagliharda	Chenab	Ramban	900	2009
Dulhasti	Kishenganga	Bandipore	390	2006
Nimo Bazgo	Indus	Leh	45	2014
Salal	Chenab	Resai	690	1986
Sewa—III	Sewa	Kathua	120	2010
Uri-II	Jhelam	Baramula	240	1997
Himachal Pradesh				
Baira Siul	Bairat, Bhaleed, Ravi	Chamba	180	1981
Bhakra	Satluj	Bilaspur	1325	1963
Chameera I	Ravi	Chamba	540	1994
Chameera II	Ravi	Chamba	300	2003
Chameera III	Ravi	Chamba	231	2012
Karchami Wangtoo	Ravi	Kinnur	1091	2011
Kol	Satluj	Balaspur	800	2014
Largi	Beas	Mandi	126	2006
Malani	Ravi	Kullu	86	2001
Nathpa Jhakri	Satluj	Kinnur	1500	2001
Pandoh	Beas	Mandi	990	1977
Parbati-III	Sainj	Kullu	520	2014
Pong	Beas	Kangra	396	1974
Uttrakhand				
Dhauliganga	Dhauliganga	Pithoragarh	280	2005
Koteshwar	Bhagirathi	Tehri Garhwal	400	2011
Ramganga	Ramganga	Gaghwal	190	1974
Ichari	Tons	Dehradun	360	1972
Maneri	Bhagirathi	Uttarakashi	90	1984
Tehri	Bhagirathi	Tehri Garhwal	1000	2005
Sikkim, West Bengal and Arunachal Pradesh				
Rangit III	Rangit	WEST	60	2000
Teesta-V	Teesta	NORTH	170	2007
Teesta-IV	Teesta	Darjeeling	160	2016
Ranganadi	Ranganadi	Papum Pare	405	2001

Apart from being the habitat of the Tibetan wolf, Bearded vulture, and White-rumped vulture, Himachal Pradesh also houses rare avian diversity such as the Koklass pheasant, Himalayan quail, and Himalayan monal indigenous to this region. The presence of such diverse species emphasizes the ecological significance of Himachal Pradesh.

Encompassing both terrestrial and avian species, Uttarakhand, among the former, Peter's tube-nosed bat, the Fishing cat, and the majestic Tiger are the most iconic. The Snow leopard and the Indian elephant are other notable mentions. Avian species like the Serow, Pygmy, and the Himalayan tahr also call this region home. The presence of varied species in the region demonstrates its habitat diversity.

Sikkim, West Bengal, and Arunachal Pradesh are collectively marked by a high density of endangered fauna. The Tibetan wolf, Red fox, and the Clouded leopard are some of the prominent mammals. The region also provides habitat to the Red panda, Fishing cat, and the rare Tibetan Gazelle. The area is further famous for its bird species, including the Bengal florican and the Black-necked crane. Such diversity indicates the richness and significance of the biodiversity in this region.

Since the Indian Himalayan region is a reservoir of biodiversity, it is imperative to underscore the gravity of the situation wherein a substantial number of species find themselves on the brink, designated as endangered or vulnerable. Each species, irrespective of its conservation status—be it critically endangered, endangered, or merely near-threatened—holds a pivotal place in upholding the ecological equilibrium of its habitat. Hence, our endeavors ought to converge on the conservation of their natural habitats, staunching the relentless tide of poaching and enlightening local communities about the indispensability of these species to our shared ecological future.

3 Major Dams in the Indian Himalayan Ecosystem

While hydroelectric plants represent a sustainable transition in the energy landscape, the criteria for designating a dam as "major" or "large" varies. The International Commission on Large Dams (ICOLD) defines a large dam as one exceeding 15 m in height from its foundation or between 5 and 15 m with a reservoir volume above 3 million cubic meters. Conversely, India's Central Water Commission (CWC) terms a "major dam" as one over 15 m from its foundation or 10–15 m with a storage capacity of over 60 million cubic meters (www.icold-cigb.org). The following section overviews major dams built in the Indian Himalayan region.

3.1 Hydropower Infrastructure and Development in Jammu and Kashmir

Jammu and Kashmir holds a significant hydropower potential, estimated at 20,000 MW (Nisar & Monroy, 2012). The Baglihar Hydroelectric Power Plant is located on the Chenab River in the Ramban area (Table 1). This run-of-the-river power station was initially proposed in 1992 and approved in 1996, with construction commencing in 1999. The plant boasts a capacity of 900 MW (JKPDC, 2017). Another prominent installation is the DulHasti hydroelectric power station, with a capacity of 390 MW, situated in Kishtwar. Developed by NHPC, this run-of-the-river facility on the Chenab River operates within a rugged Himalayan landscape, quite distant from major cities in the Jammu Division. Comprising a 70-m gravity dam, the water from the dam flows through a 9.5-km headrace tunnel before reaching the power plant and eventually being released back into the Chenab. Constructed between 1985 and 2007, the energy it produces benefits several states, including Jammu and Kashmir, Punjab, Haryana, Uttar Pradesh, Uttarakhand, Rajasthan, Delhi, and the Union Territory of Chandigarh (NHPC, 2016).

In the Union Territory of Ladakh, the Nimoo Bazgo Power Project is a noteworthy installation on the Indus River. Situated 75 km from Leh in the village of Alchi, its foundation was laid in 2001, and approved in 2005, with construction starting in 2006. With a power capacity of 45 MW, all of its units are now operational. Notably, this project was inaugurated in 2014 (PIB, 2019).

Another significant project is the Salal Hydroelectric Power Station on the Chenab River in the Reasi District (Table 1). Recognized as the maiden hydropower project in Kashmir developed by India under the Indus Water Treaty stipulations (Dar, 2011), its construction followed a 1978 agreement with Pakistan. With a power capacity of 690 MW, 1.5% of its electricity production supplies Jammu and Kashmir, while the rest is distributed through the Northern Grid to various other states.

The Sewa-II hydroelectric power plant, with an output capacity of 120 MW, stands in the Mashka region of Kathua district on the Sewa River, a Ravi River tributary. Developed by NHPC Limited, this plant boasts a gravity-style concrete dam (Encardio-Rite, 2023).

Lastly, the Uri-II hydroelectric plant in the Baramulla District serves as the second run-of-the-river power project on the Jhelum River. Positioned in the Uri area and established downstream of the already operational 480 MW Uri-I power plant (commissioned in 1997), this state-owned facility by NHPC houses four 60 MW generation units. The Uri-II power plant aims to generate 1123.76 million units of electricity annually, distributing power across a diverse range of states: Jammu and Kashmir, Haryana, Himachal Pradesh, Uttarakhand, Uttar Pradesh, Delhi, Punjab, Rajasthan, and Chandigarh, all managed by NHPC. This extensive electricity distribution showcases the project's regional impact and contribution to power supply reliability.

3.2 Hydropower Projects in Himachal Pradesh: An Overview

Himachal Pradesh boasts a formidable hydro potential, estimated at 27,436 MW (Est & Tonnes, 2018). One major project harnessing this potential is the Baira Siul Power Station (Table 1). This station taps into the combined inflow of the Baira, Siul, and Bhaledh tributaries of the Ravi River, with a total installed capacity of 180 MW (3 × 60 MW). It is expected to produce 779.28 MUs of energy annually with 90% reliability and 95% installed capacity availability. The project, headquartered at Surangani, was initiated by the Central Government in 1970–1971, and by 1981 all three units were operational.

The iconic Bhakra Dam near Bilaspur is a concrete gravity dam on the Satluj River. This 226-m-high dam forms the Gobind Sagar reservoir and has a power capacity of 1325 MW. The Chamera Dam spans the River Ravi, assisting the local hydroelectric project in the Chamba district. With its reservoir, Chamera Lake, the dam powers multiple stages: Chamera-I (540 MW), Chamera-II (300 MW), and Chamera-III (231 MW). The first phase was completed in 1994, while the third stage produced electricity in 2012.

In the Kinnaur region, the Sutlej River is home to the Karcham Wangtoo Hydroelectric Plant, boasting a 1091 MW capacity (Table 1). It is a run-of-the-river project, i.e., a hydroelectric power generation method with little to no water storage. Instead of relying on a reservoir's stored water, a run-of-the-river system relies on the natural flow and elevation drop of a river or stream to generate electricity. It is strategically placed between the 300 MW Baspa II Hydroelectric Plant and the 1500 MW Nathpa Jhakri Dam on Satluj. Similarly, the Larji Hydroelectric Power Project in the Mandi District leverages the Beas River with a design capacity of 126 MW.

Further, the Pandoh Dam, an embankment dam on the Beas River, plays a pivotal role in hydroelectricity production. As a run-of-the-river power design, it diverts the Beas River through a vast network of tunnels to the Dehar Power House with an impressive 990 MW capacity.

Near Barmana, the Kol Dam Hydropower Station is an embankment dam on the Sutlej River. With an 800-MW power plant, its construction started in 2000 and concluded in 2015. The Parbati-III Power Station also utilizes multiple rivers and nallahs to generate 520 MW of electricity.

Lastly, the Pong Dam, or Beas Dam, is an earth-fill embankment structure on the Beas River. Constructed in 1974, it was India's tallest at that time. Apart from irrigation, the dam supports a 396 MW power plant. The resultant lake, Maharana Pratap Sagar, also doubles as a renowned bird sanctuary.

3.3 Comprehensive Overview of Uttarakhand's Dam Infrastructure

Uttarakhand boasts a hydropower potential of over 20,000 MW, of which only 3900 MW has been harnessed (Mongabay). This utilization represents approximately one-third of the state's total installed capacity.

Located near Dharchula and the borders with Tibet and Nepal, the Dhauliganga Dam stands on the Dhauliganga River as a concrete-faced rock and earth-fill embankment dam (Table 1). It is a run-of-the-river dam with minimal pondage (NHPC, 2016). This dam was constructed through a collaboration between Bauer Maschinen, Daewoo Engineering and Construction, and Kajima Construction Corporation, Ltd. Additionally, the HCC, Hindustan Construction Company, and Samsung Corporation [E&C] Group joined forces to erect HRT & PH. The dam generates a total of 280 MW of hydropower (4 × 70 MW).

Situated 13 km north of Dakpathar, the Ichari Dam is a concrete gravity structure on the Tons River. Completed in 1972, it was primarily established for hydroelectric generation. This dam diverts water from the Tons River, supplying the Khodri Power Station (120 MW) and subsequently the Chibro Power Station (240 MW).

Twenty-two kilometers downstream of the Tehri Dam in the Tehri District lies the Koteshwar Dam on the Bhagirathi River (Table 1). Integrated into the Tehri Hydropower Complex, this gravity dam manages the Tehri Dam's irrigation tailrace and forms the lower reservoir for the Tehri Pumped Storage Power Station. A 400 MW run-of-the-river power station is also part of this infrastructure (THDC, 2011). The project received approval in 2000, and its journey towards sustainable energy production began with the commissioning of its first generator on March 27, 2011, followed by another on March 30, 2011.

Nestled within the Pauri Garhwal district, the Ramganga Dam, recognized by the name Kalagarh Dam, stands tall as an embankment dam constructed on the Ramganga River. Located three kilometers upstream of Kalagarh and within the boundaries of the Jim Corbett National Park, this dam has a power capacity of 190 MW. Last but not least, the Tehri Dam is the pinnacle of dam structures in India and holds the title of the 12th tallest globally at 260.5 m (Table 1). This multipurpose rock and earth-fill embankment dam is positioned on the Bhagirathi River in the Tehri Garhwal district. Acting as the primary dam for the Tehri hydropower complex and THDC India Ltd, it was completed in its first phase in 2006. The Tehri Dam supports a reservoir that caters to agriculture and urban water supplies, generating 1000 MW of hydroelectricity. Presently, 1000 MW variable-speed pumped-storage systems are under construction for the dam, with the inaugural two units anticipated to be functional by 2023 (THDC, 2011). An initial assessment of the Tehri Dam Project was done in 1961 during Jawaharlal Nehru's tenure, with its design, incorporating a 600 MW power plant, finalized by 1972. Construction began in 1978 after feasibility evaluations but faced delays due to financial, environmental, and societal concerns. Technical and financial aid came from the USSR in 1986, but political turbulence later truncated this support. The project's reins were then taken over by India, initially overseen by the Uttar Pradesh Irrigation Department. Yet, in 1988, the Tehri Hydro Development Corporation was formed to spearhead the project, financed 75% by the federal government and 25% from auxiliary channels.

3.4 Hydropower Initiatives in Northeastern India: A Synopsis

The Rangit Dam is the cornerstone of the Rangit Hydroelectric Power Project Stage III, strategically situated on the Rangit River, a prominent tributary of the Teesta River, in the South Sikkim district of Sikkim (Jain et al., 2007). Completed in 1999, this run-of-the-river hydroelectric facility commenced operations in 2000 (NHPC, 2016).

Another notable project, Teesta-V, with a capacity of 510 MW in northern Sikkim, stands out as a globally acclaimed exemplar of hydropower sustainability (NHPC). This initiative, commissioned in 2008, was devised as part of a cascade of hydropower ventures along the Teesta River (Table 1). Its purpose was not only to cater to the Energy and Power Department of Sikkim but also to power various state-owned distribution enterprises in the eastern region of India.

Further downstream, the Teesta Low Dam—IV Hydropower Plant, another run-of-the-river hydroelectric station, graces the Teesta River in the Kalimpong district of West Bengal (NHPC, 2016). Venturing into Arunachal Pradesh, the Ranganadi Dam stands tall on the Ranganadi River, also known as the Panyor River. This concrete gravity diversion dam supports a run-of-the-river scheme. Integral to Stage I of the Ranganadi Hydroelectric Project, the dam lays the groundwork for the 405-megawatt Dikrong Power House. Moreover, as part of the project's envisioned Stage II, the dam is set to bolster an additional power plant of 180 megawatts, doubling as a water reservoir for Stage I.

The sections above furnish an extensive synopsis of the hydroelectric infrastructure traversing the Indian Himalayas, accentuating the vast potential and dedicated endeavors orchestrated by the nation to exploit this renewable energy reservoir (Table 1). From the captivating panoramas of Jammu and Kashmir to the undulating terrains of Himachal Pradesh and Uttarakhand, and ultimately to the diverse biomes of Northeast India, each locality has harnessed its hydroelectric potential, cultivating practices that endorse sustainable energy approaches. The mentioned projects not only assume a pivotal role in fulfilling the energy requisites of the vicinity but also underscore India's unwavering commitment to a greener and more sustainable energy destiny. As India advances in its journey towards an eco-conscious future, these hydroelectric ventures, distinguished by intricate schematics and substantial capacities, pave the way for more ingenious and sustainable energy resolutions within the nation.

4 Impacts of Dams on the Indian Himalayan Ecosystem and Mitigation Strategies

In the Indian Himalayan region, the dams' construction affects human communities and the environment in various direct and indirect ways. This section delves into the environmental and socioeconomic consequences of dam construction.

4.1 Environmental Impacts of Dam Construction in the Himalayan Region

4.1.1 General Environmental Impacts and Economic Considerations

Dams exert multiple direct and indirect pressures on the environment, manifesting as air and water pollution, deforestation, and impacts on various flora and fauna. While hydropower expansion boosts the region's economic progress, it simultaneously induces environmental degradation and sparks conflicts regarding land and water resource reallocation (Schmutz & Moog, 2018). The conversion of mountain rivers into hydroelectric project cascade disrupts the native ecosystems. Rivers are often redirected into tunnels, causing significant riverbeds to dry up. Consequently, habitats of species relying on flowing water for migration or distribution face potential devastation (Bhatt & Pandit, 2016). Like the migratory species Mahseer (Tor tor) in Himachal Pradesh, a native carp of the Indian Himalayas has also experienced disrupted migration patterns. These large dams transform habitats from flowing rivers to stagnant waters, hinder crucial migratory patterns, alter natural river flows, and lead to siltation, changing water temperatures, and habitat loss. Rivers and wetlands, vital for groundwater recharge, suffer when disrupted, affecting groundwater dynamics (Dudgeon, 2000). Additionally, these dams introduce predatory species, increase disease prevalence, and negatively impact riverine biodiversity.

4.1.2 Local Impacts: Kinnaur's Springs

The Kinnaur region in Himachal Pradesh, India, is endowed with mountainous landscapes where local springs hold immense significance. Beyond being primary sources of freshwater for nearby communities, these springs also contribute to upholding the ecological equilibrium of the region. These springs formed naturally from underground aquifers and water table replenishment processes, play a vital role in the everyday lives of the locals by meeting domestic needs and facilitating agricultural practices. Dam constructions have been linked to the drying up of these local springs (Erlewein, 2013) by altering natural underground water flows and disrupting the geology through excavation. These changes not only endanger the local environment but also affect cultural connections to water sources, posing considerable agricultural and economic challenges for the community. This underscores the multifaceted consequences of large-scale infrastructure development in fragile ecological regions.

4.1.3 Deforestation and Its Consequences: The Kol Dam

The construction of the Kol Dam brought about significant environmental changes, particularly due to deforestation linked to its development. Removing trees for the dam project had cascading effects on the ecosystem. Trees are pivotal in holding the soil together with their root systems (Erlewein, 2013). When these trees were removed for the dam's construction, the soil became more susceptible to erosion, especially during heavy rains or water run-offs.

Soil erosion, in turn, has multiple negative impacts. Firstly, it leads to land quality degradation, affecting local agriculture and reducing the land's capacity to support vegetation. As the top layer of nutrient-rich soil washes away, it can reduce soil fertility. Secondly, the eroded soil ends up in rivers and waterways, leading to siltation. This accumulation of silt in water bodies can affect aquatic life and reduce the dam's lifespan as the reservoir gets filled with sediments.

The consequences of deforestation reverberate across the wildlife habitats of Kinnaur, prompting the migration of various species and culminating in a decline in biodiversity. Furthermore, deforestation disrupts the local microclimate, leading to fluctuations in temperature and humidity. The absence of the tree canopy, which traditionally moderates the regional climate, intensifies these alterations. The aggregate impact of these environmental changes holds the potential to significantly influence local communities, affecting their livelihoods, which include farming and fishing, along with their daily lives characterized by shifts in water quality, availability, and the regional climate.

4.1.4 Flood Plains, Hydro-Meteorological Disasters, and Specific Project Impacts

The encroachment on flood plains in the Sutluj basins for dam construction has brought about environmental and socioeconomic challenges. Flood plains, by nature, act as buffer zones during high rainfall or snowmelt, accommodating excess water and preventing sudden inundations downstream. When these plains are encroached upon or altered due to large constructions like dams, it restricts the natural flow of water. This, in turn, heightens the risk of hydro-meteorological disasters. Flash floods, for instance, become more probable as the water that would usually be absorbed or slowed by flood plains now moves downstream with greater speed and volume.

Glacial Lake Outburst Floods (GLOFs) are another significant concern. These occur when the dams or natural barriers holding back glacial lakes fail, causing large volumes of water to be suddenly released. Dam constructions in such sensitive regions can either directly or indirectly contribute to conditions that increase the likelihood of GLOFs.

Delving into specific projects reveals apparent environmental aftermaths. A case in point is the Chamera hydropower project, which left a significant ecological imprint, impacting 982.50 hectares of forested land (Bhattacharyya, 2007). Forests encompass intricate ecosystems hosting a variety of plant and animal species. The loss of such an extensive forested area can disrupt local wildlife habitats, trigger soil erosion, alter microclimates, and even have implications for local livelihoods, especially if communities depend on forest resources. Additionally, the biodiversity of aquatic ecosystems has suffered. The Tehri Dam region has experienced a decline in its fish diversity. Dams can obstruct fish migration routes, reducing fish populations in specific areas. This disrupts ecological balance and affects local communities relying on fishing for their sustenance and income.

Throughout the years, especially in 2009, 2010, 2012, and 2013, Uttarakhand experienced devastating floods that many environmentalists and experts partly link to dam construction and presence. The rationale for this correlation is intricate. Large dams have the potential to alter the natural flow and sediment transport of rivers, causing sediment buildup upstream and erosion downstream. When faced with intense rainfall events, which are frequent in the monsoon-prone Uttarakhand region, the controlled or forced water discharge from dam reservoirs can worsen flooding downstream.

4.1.5 Environmental Toll of Tihri and Koteshwar Dams

The construction of the Tehri and Koteshwar dams necessitated the conversion of a significant 4193.813 hectares of forested land. However, this is not just any ordinary forest terrain; it constitutes a portion of the Himalaya—a region acknowledged worldwide for its unparalleled biodiversity. Within these forests dwell a plethora of species, many of which are exclusive to this region (endemic) and others facing threats (Kumar et al., 2018). The alteration or removal of such vast expanses of forest does not merely entail the loss of trees; it signifies a disturbance in the ecological tapestry, where each living organism, regardless of size, has a role. The disappearance of these habitats could result in a decline of species, some of which might be teetering on the edge of extinction or possess critical roles within the ecosystem.

Moreover, the Himalayas are not just about biodiversity. They play an essential role in climate regulation, act as water towers providing freshwater to millions downstream, and are central to numerous cultural and spiritual narratives. When dams alter the Himalayan landscape, they don't just change a piece of land; they influence a living, breathing ecosystem with regional and global significance.

4.1.6 EIA Process and Calls for Revaluation

The evident outcomes witnessed and experienced by the inhabitants of the region, have sparked debates and conversations concerning the Environmental Impact Assessment (EIA) process. EIA is a globally employed tool to forecast the environmental effects of a proposed project before its execution. The flooding events in Uttarakhand prompted queries about the adequacy and thoroughness of the EIA procedures that preceded the construction of these dams. Were all potential impacts taken into consideration? Were the assessments comprehensive and founded on rigorous scientific methodologies? These questions accentuate the need for a more comprehensive and accountable assessment mechanism, ensuring the thorough examination of environmental, socioeconomic, and cultural dimensions before initiating extensive infrastructural projects.

In summary, while dams can offer potential advantages, such as hydroelectric power generation and water storage for irrigation, evaluating and mitigating their environmental impacts is essential to ensure the sustainability of development.

4.2 Socioeconomic Impacts and Induced Displacement Due to Dam Construction

4.2.1 Global Perspective and Key Issues

The repercussions of dam construction ripple through societies, primarily manifesting as forced displacement and necessitating resettlement. A prevailing global concern, induced displacement often emerges as collateral damage from extensive natural resource exploitation. Multifaceted conflicts arise from land and water resource reallocation due to large dam construction (Rana et al., 2007). Central issues include the displacement of local communities with inadequate rehabilitation, loss of livelihoods, environmental degradation, and altered water flows affecting downstream communities. Additionally, the submergence of culturally significant areas exacerbates the sense of loss among affected groups. While dams bring potential economic benefits, these often bypass displaced communities, exacerbating economic disparities and raising broader concerns about rights, identity, and equitable development.

4.2.2 Sikkim's Opposition to Dam Projects

Contrastingly, in Sikkim, India, the indigenous Bhutia communities of Lachungpas and Lachenpas have successfully opposed all proposed hydropower projects in their areas, Lachung and Lachen (Dukpa, et al., 2019). Since 2003, over 168 major dams have been proposed in India's Eastern Himalayas. The push for hydropower by the Central and State Governments has caused significant conflicts in the northeast region. Many contentious projects, such as the Teesta Stage IV, Teesta Stage VI, Panam in Sikkim, Subansari Lower HEP in Assam, Tipaimukh Dam in Tripura, and the Dibang Multipurpose Project in Arunachal Pradesh, have faced delays, cancellations, or are awaiting clearance. This northeast region, rich in tribal diversity, has communities protected by Article 371 of the Indian Constitution. Still, large dam developments, seen as "development" tools, often go against the desires of these tribal groups. Such conflicts occasionally turn violent, with some anti-dam protesters losing their lives. Despite this, the Lachungpas and Lachenpas successfully halted five projects within a few years, maintaining their anti-dam stance. Yet, neighboring Dzongu, home to the Lepchas, is often highlighted in media as the central anti-dam movement in North Sikkim.

4.2.3 Impact on Nomadic Communities: Himachal Pradesh and Jammu and Kashmir

In Himachal Pradesh and Jammu and Kashmir, indigenous nomadic communities like the Gaddis and Gujjars, traditionally reliant on pastoralism and seasonal migrations, face significant disruptions due to dam constructions. These dams lead to losing vital grazing lands, forced relocations, limited access to essential natural resources, and cultural and economic challenges. Moreover, altered local ecosystems and the influx of external populations during construction put their traditional way of life and economic stability at grave risk (Sharma & Rana, 2014).

4.2.4 Gendered Impacts in Jammu and Kashmir

In Jammu and Kashmir, dam constructions have significantly impacted the women of Kathua and Pul Toda. Kathua's women, deeply involved in village economies and agriculture, faced challenges with the loss of fertile lands and diminished roles in livestock management, eroding their self-sustenance. Conversely, Pul Toda's businesswomen, who had carved a niche in local trade, grappled with the dual challenges of losing their financial independence and intensified societal constraints post-dam construction (Nisar & Monroy, 2012). This shift not only impacted their economic roles but also altered their socio-cultural dynamics and bargaining power within the community.

4.2.5 Socio-Cultural Shifts: The Kol Dam Example

The construction of the Kol Dam led to notable socio-cultural shifts within affected communities, transitioning them from traditional joint family systems to nuclear family setups. This structural change, rooted in the strains of displacement and the challenges of adapting to new environments, was intensified by their primary agricultural background. With the loss of fertile farmland and a lack of alternative skills outside agriculture, these communities, as highlighted by Thakur and Thakur, faced heightened economic vulnerabilities in their new settings, grappling with both the erosion of their cultural identity and economic stability.

4.2.6 Legacy of the Bhakra Dam

The Bhakra Dam in Bilaspur district, Himachal Pradesh, symbolizes both the triumphs and challenges of post-independence developmental initiatives in India. While its construction in the 1950s showcased India's aspirations for progress by providing irrigation and generating hydroelectric power, it also led to large-scale displacements. Mishra's 2019 study emphasizes that the resettlement plans were inadequately planned, leaving many inhabitants grappling with issues like loss of fertile land, cultural alienation, economic hardships, and fractured community bonds. The dam's legacy, thus, underscores the importance of comprehensive and empathetic resettlement strategies in developmental projects.

4.2.7 Socioeconomic and Cultural Impacts of Tihri and Koteshwar Dams

Further fueling concerns is the example of the Tehri Dam, one of the highest dams in the world. The backwater flows from this dam's reservoir, particularly near Chiniyalisaur in Uttarakhand, have had detrimental effects on the surrounding areas (Rana et al., 2007). Agricultural fields, the lifeblood of many local communities, have been adversely affected. This is crucial, as agriculture is not just about livelihood in this region; it's deeply intertwined with culture, tradition, and local socioeconomic systems. When fields get inundated or rendered less productive due to changes in the water table or silt deposition, it affects crop yields and the very fabric of the community that relies on them.

In 1979, the construction of the Tehri Dam in Uttarakhand prompted the massive displacement of thousands, submerging the old Tehri town and several villages. Despite the passage of time, rehabilitation efforts remain inadequate and marred by the absence of a holistic resettlement plan. Many relocated inhabitants, previously reliant on farming and fishing, grapple with unsuitable lands and economic uncertainties in new areas. Beyond the tangible challenges, the dam's construction has inflicted profound emotional distress. Severing connections to ancestral lands has left many yearning for their lost homes. At the same time, the dispersal of close-knit communities has led to a palpable sense of alienation and identity loss. The Tehri Dam saga underscores the vital importance of balancing developmental aims with the comprehensive well-being of the affected communities.

The construction of dams, particularly in ecologically fragile areas like the Himalayas, has adverse ecological and socio-cultural consequences. The Koteshwar

Dam serves as a poignant case in point. The dam's construction affected the inhabitants of Payal village deeply. While designed for larger development goals like power generation and water storage, such infrastructure projects often overlook or underestimate their impact on smaller communities. For the villagers of Payal, the dam not only altered their immediate environment but potentially their entire way of life, as relocation, altered livelihoods, and socio-cultural shifts became inevitable.

Dams in India symbolize the balance between development and community well-being. While they promise progress, they also cause socioeconomic and cultural disruptions. The varied reactions, from resistance in Sikkim to adaptations at Kol Dam, highlight diverse experiences. However, the need for sensitive resettlement remains clear. Development should respect and protect community rights and emotions.

4.3 Mitigating the Impacts of Large Hydroelectric Projects on Development Activities

Hydroelectric projects often wield significant influence over developmental pursuits. As elaborated above, their establishment brings about substantial social and environmental consequences. These encompass widespread displacement of families, erosion of traditional livelihoods, disruption of social bonds, and degradation of environmental conditions (Rana et al., 2007). Communities forced to relocate frequently confront reduced access to essential amenities like water, electricity, and sanitation. Once teeming with diverse flora and fauna, the local ecosystem experiences drastic changes, leading to habitat loss and contamination of water resources. Furthermore, empirical data indicates that displaced women encounter hurdles in accessing fundamental rights, including food, health, and shelter. Additionally, marginalized groups are often marginalized further during compensation processes. In this context, we present a set of recommendations aimed at alleviating these consequences.

4.3.1 Environmental Impact Analysis (EIA)

Environmental Impact Analysis (EIA) has emerged as a fundamental mechanism for assessing the consequences of hydroelectric projects, revealing their advantages and disadvantages. A comprehensive EIA not only delineates the range of impacts but also proposes feasible solutions that can garner the endorsement of all stakeholders—ranging from project developers and financers to local communities and government bodies. Thus, it's imperative to undertake a robust EIA to discern the full spectrum of a project's ramifications rather than blanket endorsements or rejections of developmental endeavours.

A robust EIA should provide a holistic analysis, capturing not only environmental consequences but also socioeconomic and cultural impacts. Incorporating a cumulative impact assessment can shed light on the combined effects of multiple projects on river ecology and local microclimates. Local communities can voice their concerns by fostering a participatory approach, leading to better project design or more effective rehabilitation measures. Given the region's biodiversity and vulnerability to climate change, EIAs must assess potential losses in flora and fauna, changing precipitation patterns, and glacial melt rates. Simultaneously, they should factor in seismic risks, downstream effects, and economic displacements, focusing on the broader well-being of the Himalayan ecosystem and its inhabitants. Emphasizing enforcement, transparency, and adaptive management in the EIA can ensure that dam construction in the Himalayas is both sustainable and accountable.

4.3.2 Stakeholder Consultation

Stakeholder consultation is pivotal in mitigating the environmental and socioeconomic impacts of large dams in the Indian Himalayas. It ensures that the voices, concerns, and aspirations of affected communities are acknowledged and integrated into project designs. A more comprehensive understanding of potential environmental and socioeconomic disruptions can be gained by involving local inhabitants who intimately understand the landscape, water resources, and traditional land uses.

Stakeholder consultation provides insights into the potential loss of livelihoods, cultural sites, and traditional knowledge. This feedback can guide the creation of effective rehabilitation and resettlement plans, ensuring equitable compensation and assistance for transitioning to new livelihoods.

It can foster trust and collaboration between project developers and local communities. This mutual understanding can reduce conflicts, project delays, and the potential costs associated with social unrest or litigation. In the context of environmental impacts, stakeholder feedback can highlight less obvious consequences, such as subtle shifts in local microclimates, has implications on non-commercial species, or threats to medicinal plants and herbs.

Involving a broad range of stakeholders, including environmental experts, scientists, local NGOs, and indigenous representatives, ensures a multidisciplinary approach. Such a diverse consultation can help identify sustainable construction practices, better site selection, and potential mitigation measures that may be overlooked in a more limited assessment. Stakeholder consultation provides a platform for holistic, inclusive, and forward-thinking decision-making, crucial for minimizing the adverse impacts of dam constructions in the sensitive ecosystem of the Indian Himalayas.

4.3.3 Infrastructure Development in Resettlement Colonies

Infrastructure development in resettlement colonies can significantly mitigate the environmental and social impacts of large dams in the Indian Himalayas. Before initiating relocations, the onus lies on project authorities and governmental agencies to establish well-equipped resettlement colonies. Ensuring that these colonies are provided with essential services, from healthcare and education to sanitation and electricity, can significantly attenuate the hardships displaced individuals face.

Adequately designed infrastructure provides a foundation for the sustainability and well-being of displaced communities. For instance, ecologically sensitive waste management, efficient transportation networks, and sustainable energy sources can minimize environmental harm. Simultaneously, creating educational and healthcare facilities ensures community development and health, while agricultural and market infrastructure helps restore livelihoods. Additionally, constructing community and cultural centers fosters social cohesion, preserving traditions, and establishing feedback mechanisms for continued community engagement. In sum, holistic infrastructure development in resettlement areas can transform challenges of displacement into opportunities for sustainable growth and social integration.

4.3.4 Education Continuity

Ensuring education continuity in the wake of large dam constructions in the Indian Himalayan region is vital for mitigating both immediate and long-term socio-environmental impacts. Education provides the tools and knowledge essential for communities to adapt to changing environments and find sustainable solutions to new challenges. By guaranteeing uninterrupted learning, displaced children, especially girls who often face heightened vulnerabilities, can continue to acquire skills and knowledge crucial for their personal and community's future. This educational continuity can foster a sense of normalcy amid upheaval and, in the long run, empower these children to become stewards of their environment and advocate for sustainable development in their communities.

4.3.5 Women's Participation in Decision-Making

Throughout history, women have held significant roles within their communities, contributing extensively to the socio-cultural and economic aspects. They have frequently served as primary caregivers and played crucial roles in agriculture, water management, and household economics. Consequently, they possess unique insights into the nuanced challenges that displacement can introduce. By ensuring women's participation in decision-making, especially concerning compensation allocations, projects can be more attuned to the real-world needs and priorities of the entire community, leading to better-tailored, equitable, and sustainable solutions. Their inclusion fosters a comprehensive understanding of the social dynamics, enabling policies and interventions that reflect the complexities of affected communities.

5 A Closer Look at the Dauliganga Basin Amid the Proposed Large Dams

The Dhauliganga basin stands out for its hydrological significance in the Uttarakhand region. The Dhauliganga is the most prominent headwater tributary that feeds into the Alakananda downstream. Its source, the Kamet glacier above 6060 m, not only breathes life into Dhauliganga but also contributes through its Geldhong (Gal) originating branch. As the Dhauliganga River progresses southwestward, it meets the waters from a right bank tributary near Shepak Kharak, maintaining this course until Khal Kurans. Further downstream, at Gamsali, the river welcomes the Amrit Ganga, which originates from the Deoban glacier, joining the Dhauliganga on its right bank. Upon reaching Kuikuti, the river integrates the flows from Girthi Ganga on its left side. Ultimately, the Dhauliganga meets the Alaknanda River at Vishnuprayag on the left bank at an altitude of 1440 m (THDC, 2011).

The Dhauliganga River, nestled in the ecologically sensitive and seismically active Himalayas, is a pivotal case study for evaluating the ramifications of large dams. Its unique location offers insights into potential ecological shifts, seismic risks, and the impacts on indigenous communities, whose culture and livelihoods could be uprooted by such projects (Jha & Khare, 2016). Moreover, the religious and cultural importance of rivers in this region, the Dhauliganga's role in water supply, and its susceptibility to climate change-driven glacial melting highlight the necessity of investigating its hydrological shifts after dam construction. Assessing the interplay between Dhauliganga's dam construction and its multifaceted implications can guide sustainable and equitable developmental strategies for similar Himalayan projects.

5.1 An Overview of the Hydroelectric Projects of Dhauliganga Basin

In the Dhauliganga basin of Uttarakhand, several significant hydroelectric projects have been developed or proposed. Among these are the Tapovan Vishnugad Hydropower Plant, managed by NTPC and expected to offer a capacity of around 520 MW upon completion. Tehri Hydro Development Corp. Ltd. (THDC, 2011) is planning the Malari Jelam H.E. Project with a 65 MW capacity, while the Jelam Tamak H.E Project is set to harness the hydroelectric potential between the Jelam and Tamak villages in the Chamoli district.

5.1.1 Tapovan Vishnugad Hydropower Plant

The Tapovan Vishnugad Hydropower Plant, located on the Dhauliganga River near Joshimath in Uttarakhand's Chamoli district, boasts a planned capacity of 520 MW. As a run-of-the-river scheme, its key components comprise a barrage, headrace tunnel, underground powerhouse, and tailrace tunnel. Developed by India's state-owned NTPC Limited, the project aims to address the peak energy demands of the northern grid and stabilize the region's electrical infrastructure. However, the initiative had encountered delays due to geological and other challenges. Notably, the project's environmental and social implications, including potential displacement of local communities, ecological disturbances, and changes in river flow patterns, emphasize the balance needed between meeting energy demands and minimizing adverse impacts.

5.1.2 Malari Jelam H.E. Project

The Tehri Hydro Development Corp. Ltd. (THDC) aims to construct a 65 MW hydroelectric power plant in Uttarakhand, India. This ambitious project encompasses the development of a substation, powerhouse, access roads, a barrage, a water conductor system, a horseshoe-shaped head race tunnel, an underground machine hall, and a tailrace tunnel. Equipment installation will include generators, transformers, turbines, a gated power intake, a desilting chamber, a surge shaft, and a pressure shaft, complemented by the laying of transmission lines. In 2010, due to opposition from Malari villagers, the project location shifted to Kosa Village, a kilometer from the original site. By April 2011, a power sector task force instructed THDC to ensure timely project completion. The MoEF, in 2012, advised a 1 km gap between the Malari Jhelum's Tail Race Tunnel (TRT) and the Full Reservoir Level (FRL) of the Jelum Tamak Project. The viability report for 65 MW was submitted to the Central Electricity Authority (CEA) by May 27, 2013, initializing the DPR process. In August 2013, a Supreme Court directive halted any environmental or forest clearances for Uttarakhand hydro projects. However, by February 11, 2014, THDC secured clearance from the CEA. A petition was filed in the Supreme Court by THDC on September 6, 2014, to revisit the MoEF clearance issue. The project awaits the Supreme Court's verdict to proceed with DPR preparation.

5.1.3 Jelam Tamak H.E. Project

The Jelam Tamak H.E. Project aims to harness the hydropower potential of Dhauliganga between Jelam and Tamak villages in the Chamoli district. The proposal involves diverting Dhauliganga River through a water conductor system on its right bank. Three 36 MW units, totaling 108 MW, are planned for an underground powerhouse on Dhauliganga's right bank. The blueprint details a barrage, 28 m in height and 83 m in length, at an altitude of 2623.50 m, a 4.40 km long horseshoe concrete-lined head race tunnel, an underground powerhouse, and a 308 m long tailrace tunnel. The system aims to utilize a design discharge of 57.58 m^3/s and a drop of approximately 207.54 m for power generation, with an annual energy generation in a 90% dependable year estimated at 505.12 GWh. The catchment area for the Jelam Tamak H.E. Project spans 1666 km^2.

5.1.4 Lata Tapovan H.E Project

The Lata Tapovan Hydroelectric Project is a significant hydroelectric initiative located in the Dhauliganga basin of Uttarakhand. With a planned capacity of 171 MW, it is a run-of-the-river scheme situated approximately 25 km from Joshimath in the Chamoli district. The government of Uttaranchal (now Uttarakhand) allotted the project in August 2003, prompting site-specific studies and investigations to prepare the Detailed Project Report (DPR) and ascertain its techno-economic viability. The project implementation agreement was formalized between NHL and the state government in November 2005. The anticipated cost per MW for this endeavor is projected at 4.63 crore. As of the latest information, the DPR for the project had been formulated, essential project/site-specific clearances were obtained, and land acquisition for the project was underway, with township infrastructure development in progress.

The Dhauliganga basin, situated at the heart of the Himalayan region, showcases nature's abundant resources. Numerous hydroelectric ventures tapping into the river's kinetic energy underscore the importance of sustainable power generation in the area. These undertakings not only contribute to the electricity grid but also play a pivotal role in the socioeconomic advancement of Uttarakhand. However, while their potential benefits are substantial, it remains essential to prioritize ecological balance, local heritage, and community well-being in the quest for developmental progress.

5.2 Forest Types in Dhauliganga Basin

In the Dhauliganga Basin, the diverse topography and altitude variations give rise to distinct forest types, each harboring a unique combination of flora. Moist Deodar Forests are predominantly found at altitudes ranging between 1500 and 2000 m. Characterized by more or less pure stands of deodar trees, these forests play a crucial role in maintaining the region's ecological balance. Their impressive stature and dense canopies make them a key feature of the Dhauliganga landscape.

Moving on to the Dry Temperate Coniferous Forest, this type is primarily composed of coniferous trees punctuated by a few broad-leaved trees and shrubs. Noteworthy species that make up these forests include *Cedrus deodara*, *Fraxinus xanthoxyloides*, *Hippophae salicifolia*, *Pinus wallichiana*, and *Populus ciliata*. The understory, although not as dense, features shrubs like *Berberis aristata* and *Ephedra gerardiana*, adding layers of biodiversity to the forest structure.

The West Himalayan Dry Juniper Forest is another distinctive forest type. These forests are open and evergreen, mainly situated above Malari in the Niti area and spanning altitudes from 2800 to 4300 m. *Juniperus macropoda* dominates these terrains, occasionally forming pure stands. The undergrowth comprises a range of xerophytic shrubs, including *Berberis petiolaris* and *Hippophae salicifolia*, each adapted to the harsher climatic conditions of this altitude.

The West Himalayan Birch/Fir Forests offer a contrasting sight. These irregular forests predominantly occupy regions above 3000 m, particularly in areas like Dronagiri and Malari. Trees such as *Abies pindrow* and *Betula utilis* are common sights, with woody plants like *Rosa sericea* adding diversity to the forest floor.

The Sub-Alpine Pastures represent a unique biome in the Dhauliganga Basin. These expansive meadows are a riot of herbs and grass species found below the timberline in the sub-alpine zone. From *Aconitum atrox* to *Taraxacum officinale*, these pastures not only serve as grazing grounds but also contribute to the region's rich biodiversity.

5.3 Floral and Faunal Diversity in the Dhauliganga Basin

5.3.1 Floral Diversity and Socio-Ecological Interactions in the Dhauliganga Basin

The Dhauliganga Basin has a unique and diverse floral composition shaped by its varying topography and climatic influences. Within the broader spectrum of flora in Uttarakhand, there are about 116 endemic species of flowering plants, such as the herbaceous members of the Caryophyllaceae family, *Arenaria curvifolia* and *A. ferruginea,* found primarily above 3000 m. Notably, the *Geranium polyanthes* of the Geraniaceae family thrive between 2500 to 4500 m (Table 4). Among the shrubs, *Cotoneaster garhwalensis* from the Rosaceae family is prominent between 2700 and 3700 m. Furthermore, the Dauliganaga region hosts unique grasses such as *Calamagrostis garhwalensis* and *Festuca nandadevica* from the Poaceae family, seen between 2500 and 3550 m.

The medicinal plants of this region are equally fascinating. From the Berberidaceae family, the Berberis aristata, locally known as Daru-haridra, thrives up to 2500 m (Table 4). The Violaceae family's *Viola biflora*, named Vanfsa locally, is seen between 2500 and 3500 m. Another notable herb is *Astragalus candolleanus*, or Rudravanti, from the Fabaceae family, found between 2600 and 4000 m. The Rosaceae family offers medicinal plants like *Potentilla fulgens*, locally termed Vajardanti, and *Prinsepia utilis* or Bhenkla, which flourished between 1500 and 2800 m. The Cupressaceae's *Juniperus recurva* or Dhoop can be located from 2600 to 3600 m. Lastly, *Ephedra gerardiana* from the Ephedraceae family, known as Somvalii locally,

Table 4 Detail of endemic plant species and those with medicinal significance found within the Dhauliganga basin

Family	Endemic Species	Habit	Altitude
Caryophyllaceae	*Arenariacurvifolia* *A. ferruginea*	Herb Herb	3300–3650 Above 3000
Geraniaceae	*Geranium polyanthes*	Herb	2500–4500
Rosaceae	*Cotoneaster garhwalensis*	Shrub	2700–3700
Cyperaceae	*Carexnandadeviensis*	Herb	2000–3000
Poaceae	*Calamagrostis garhwalensis* *Festuca nandadevica*	Grass Grass	2500–3500 3500–3550
Family	Medicinal plant	Local name	Altitude
Berberidaceae	*Berberis aristata*	Daru-haridra	Up to 2500
Violaceae	*Viola biflora*	Vanfsa	2500–3500
Fabaceae	*Astragalus candolleanus*	Rudravanti	2600–4000
Rosaceae	*Potentilla fulgens* *Prinsepia utilis*	Vajar-danti Bhenkla	1600–2600 1500–2800
Cupressaceae	*Juniperus recurva*	Dhoop	2600–3600
Ephedraceae	*Ephedra gerardiana*	Somvalii	2500–3500

finds its habitat between 2500 and 3500 m. These plants not only add to the ecological diversity but also hold immense medicinal importance for local and global communities.

While the region's floral diversity is commendable, it's also home to some Threatened Flora. The Red Data Book of India identifies two such species, *Allium stracheyi* and *Taxus baccata*, that reside within the project and catchment area. Their precarious status is exacerbated by habitat destruction and unsustainable harvesting practices, placing many invaluable species on the brink.

The relationship between the local populace and the flora cannot be understated. Many of the basin's plants have Economic Importance. Local communities not only rely on these plants for their basic needs, spanning from food and fodder to fuel and timber, but they also actively cultivate several of these beneficial species, emphasizing their intertwined existence.

Further enriching the basin's botanical tapestry are its Medicinal Plants. Uttarakhand's wealth in medicinal plant diversity is well-documented, and the Dhauliganga Basin is no exception. Indigenous tribes and local residents, especially those near forest areas, have a storied tradition of harnessing these plants to remedy various health concerns. It's noteworthy that even though the project area might be classified as a degraded, dry semi-arid zone, it still offers a haven for many plants with potent medicinal properties.

5.3.2 Faunal Splendors of the Dhauliganga Basin: A Confluence of Biodiversity

The Dhauliganga Basin, spanning from temperate to alpine zones, presents a tapestry of diverse habitats, from snow-covered regions above the timberline in winter to terraced cultivation valleys dotted with settlements. This range of ecosystems hosts a rich variety of faunal species (Table 5). In the mammalian realm, the Rhesus macaque (*Macaca mulatta*) predominantly inhabits areas up to 2500 m and is classified as 'Least Concern' by IUCN, enjoying protection under Schedule II of the Wildlife Protection Act (WPA). The Common langur (*Semnopithecus entellus*), however, residing up to 3500 m, faces more significant threats, being categorized as 'Endangered' by IUCN and safeguarded under Schedule I of WPA. Interestingly, species like the Goral (*Naemorhedus goral*), spanning regions between 2100 and 3000 m, are considered 'Near Threatened' and find their place in Schedule III of WPA.

High-altitude mammals, like the Argali and Blue sheep, reside around the 4000 m mark and are identified as 'Vulnerable' (Table 5). Their conservation importance is emphasized by their placement under Schedule I of WPA. The Common Leopard (Panther pardus) and Snow Leopard (Panther uncia) are equally significant. While the former thrives up to 3000 m, the latter is adapted to regions above this altitude. Both species have been flagged as 'Vulnerable' by the IUCN, with the Snow Leopard additionally bearing an 'Endangered' tag. Their critical ecological roles warrant their protection under Schedule I of WPA.

The Brown bear (*Ursus arctos*) occupies habitats below 5000 m. While it has a 'Least Concern' status by IUCN, the Zoological Survey of India (ZSI) categorizes it as 'Endangered'. Similarly, the Alpine musk deer (*Moschus chrysogaster*), whose habitat ranges between 3000 and 5000 m, is deemed 'Endangered' by both regulatory bodies and is accorded the same protective status as the leopards. The Himalayan tahr (*Hemitragus jemlahicus*), spanning regions from 2500 to 5000 m, also shares this protective status, reflecting its ecological significance.

Turning our attention to avian species, we find the region graced by the presence of the majestic Lammergeier (*Gypaetus barbatus*) (Table 5). Bearing an 'Endangered' status by IUCN, it is safeguarded under Schedule I of WPA. The vibrant Monal pheasant (*Lophophorus impejanus*) shares the same IUCN classification but finds its protection under Schedule IV of WPA. With its distinct calls, the Cheer pheasant (Catreus wallichi) mirrors the Lammergeier's protective status. Lastly, although' Vulnerable', the Koklas pheasant (Pucrasia macrolopha) enjoys protection under Schedule IV of WPA.

The avifaunal spectrum around the proposed JelamTamak H.E. Project area is diverse and vibrant. The region is a haven for various bird species, ranging from the majestic hawks, vultures, falcons, and eagles to the more petite partridges, pigeons, doves, and cuckoos. The lush greenery and unique topography also attract barbets, drongoes, mynas, tits, sparrows, tree pies, magpies, thrushes, bulbuls, flycatchers, finches, wagtails, and forktails, creating an ornithologist's paradise.

Despite the catchment area of the Jelam Tamak H.E. project not being particularly rich in herpetofauna, the influence zone in its lower reaches is believed to

Table 5 Details of threatened mammal and bird species found in the Dhauliganga basin and their conservation status as per guidelines of the International Union for Conservation of Nature (IUCN), Zoological Survey of India (ZSI), and Wildlife Protection Act (WPA)

	Scientific name	Distribution	IUCN status	ZSI status	wpa status
Mammalian species					
Rhesus macaque	*Macaca mulatta*	2500 m	LC	–	II
Common langur	*Semnopithecus entellus*	3500 m	EN	–	I
Wild boar	*Sus scrofa*	1500 m	LC	–	–
Goral	*Naemorhedus goral*	2100-3000 m	NT	–	III
Barking deer	*Muntiacus muntjak*	1500-2400 m	LC	–	–
Argali and blue sheep		4000 m	VU	–	I
Common Leopard	*Panther pardus*	3000 m	VU	VU	I
Snow leopard	*Panther uncia*	above 3000 m	EN	EN	I
Jungle cat	*Felis chaus*	2000 m	LC	–	II
Wolf	*Canis lupus*	Lower and middle part	LC	–	I
Jackal	*Canis aureus*	1200–2100 m	LC	–	–
Common otter	*Lutra lutra*	3600 m	NT	–	–
Indian flying fox	*Pteropus giganteus*	3600 m	LC	–	–
Brown bear	*Ursus arctos*	Below 5000 m	LC	EN	I
Serow	*Capricornis sumatraensis*	1500–4000 m	VU	VU	I
Bharal	*Pseudois nayaur*	4200–4700 m	LC	VU	I
Alpine musk deer	*Moschus chrysogaster*	3000–5000 m	EN	EN	I
Indian porcupine	*Hystrix indica*	Below 2400 m	VU	–	II
Himalayan tahr	*Hemitragus jemlahicus*	2500–5000	VU	EN	I
Avifaunal species					
Lammergeier	*Gypaetus barbatus*	–	–	EN	I
Monal pheasant	*Lophophorus impejanus*	–	–	EN	IV

(continued)

Table 5 (continued)

	Scientific name	Distribution	IUCN status	ZSI status	wpa status
Cheer pheasant	*Catreus wallichi*	–	–	EN	I
Koklas pheasant	*Pucrasia macrolopha*	–	–	VU	IV

(**LC**- least concern; EN- endangered; **NT**- near threatened; **VU**- vulnerable; and **Schedule I**- endangered species needing rigorous protection; **II**- high protection, trade prohibited; **III**- Protected species, the penalty for violation of the act is less; **IV**- vermin, hunting permitted; **- not defined**)

be home to an array of amphibian species, including *Rana annadalei*, *R. blanordii*, *R. leibigii*, and *R. minica.* The reptilian community here is represented by species such as hemidactylus brooks, *H. flaviridis*, *Agama tuberculata*, *Japalura major*, and *Scincella himalayanum*, along with a few others like *Vipera russelli*, highlighting the basin's herpetological significance.

The species mentioned offer a glimpse into the region's ecological richness. Ensuring their conservation is not just a matter of preserving biodiversity but also an imperative for maintaining the health of the entire ecosystem.

5.4 Ecological Vulnerabilities and Impacts in the Dhauliganga Basin

5.4.1 Vulnerability of Dhauliganga Basin

The Dhauliganga basin stands as the youngest chapter in the grand narrative of the Ganga River. Currently in its youthful stage, the river holds immense potential for establishing hydropower plants and dams (Jha & Khare, 2016). However, the pristine environment, mixed major types of forests, and habitats for many vulnerable and youthful animals make ecological decisions complex. Beyond its faunal richness, the basin is a reservoir of medicinal and economically valuable plant species. Fortunately, anthropogenic involvement remains minimal, preserving its delicate balance. Yet, the region has challenges; it's a hotspot for landslides and Glacial Lake Outburst Floods (GLOFs). Further highlighting its ecological significance is the proximity of the Nanda Devi Biosphere Reserve.

5.4.2 Impacts of Hydroelectric Plants in Dhauliganga Basin

Introducing the H.E. plant in the Dhauliganga Basin brings along ecological concerns (Pandey et al., 2021; Thakur et al., 2016). Foremost among these is the anticipated species loss. The direct activities aligned with the project's execution could adversely affect the native species of the construction zones. Adjacent to the issue of species loss is the probable habitat degradation and loss. The continual stream of construction and the various ancillary operations are expected to affect the natural habitats adversely. The rampant disposal of non-biodegradable waste coupled with the emissions of harmful pollutants, such as SPM, NOx, SOx, and CO, would further amplify the threat. Furthermore, the escalating noise levels and sweeping changes in land use patterns underline the gravity of this concern. Even though these negative impacts are severe, a ray of optimism is, as they are perceived to be temporary and reversible.

Yet, the installation of the plant not only threatens to degrade habitats but also fragments them. The surge in human activities and the sheer volume of project-related operations might severely restrict the unhindered movement of the resident fauna. This fragmentation is not just a physical barrier but has profound ecological implications. While geographically localized, these ramifications are distressingly irreversible (Grumbine & Pandit, 2013; Pandit & Grumbine, 2012).

Finally, the basin's diverse wildlife faces a direct challenge from the project. Activities intrinsic to the project, like blasting and road construction, along with increased vehicular movement, are expected to generate noise levels that could surpass the 90 dB mark. The inherent nature of the basin's wildlife, which includes elusive species such as the musk deer, Tahr, and black bear, among others, is to seek tranquillity. Such heightened disturbances could severely impact their natural behaviours, especially critical breeding activities. The fallout of these project activities on the basin's wildlife is devastatingly irreversible.

5.5 Balancing Energy and Ecology in the Dauliganga Basin

5.5.1 Integrated Resource Planning (IRP)

Balancing the Dauliganga Basin's energy ambitions with preserving its unparalleled ecological gems demands a comprehensive strategy, intertwining technological advancements, sustainable practices, and active community participation. An essential step is the development of an Integrated Resource Planning (IRP) that weighs the energy, economic, and environmental facets of diverse energy sources, highlighting those with minimal basin impact.

For example, rather than resorting to vast dams, the focus could shift to smaller, run-of-the-river hydropower schemes, known for their milder environmental and societal repercussions. Moreover, infrastructure should embrace designs that foster fish migration and sediment transport, such as fish ladders and sediment bypass tunnels. Simultaneously, for any habitat disruptions caused by energy endeavors, counteractive habitat restoration within the basin should be an obligation.

5.5.2 Strategic Environmental Assessments

Furthermore, implementing Strategic Environmental Assessments (SEAs) before any project initiation ensures the seamless integration of conservation priorities from the beginning. Implementing continuous, real-time monitoring mechanisms for water quality, sediment, and biodiversity and adopting adaptive management strategies based on current ecological data and feedback can offer a dynamic approach to conservation.

5.5.3 Community Engagement, Public Awareness and Strengthening Legal Framework

Equally vital is the engagement of local communities in conservation efforts, valuing their indigenous knowledge while ensuring they reap direct benefits from projects. By building the capacity of local communities and stakeholders through training in sustainable resource management and establishing economic incentives, such as eco-tourism and payments for ecosystem services, the basin's conservation can become a shared responsibility and benefit. Collaborative efforts involving governments, NGOs, communities, and the private sector can ensure profitable and environmentally sound energy projects. Public awareness campaigns can further rally broader support by emphasizing the basin's ecological significance and the imperative balance between development and conservation. Strengthening the legal framework with rigorous regulations, coupled with penalties for non-compliance and solid project oversight, is another pillar of this balanced approach. Further, an investment in research and development can lead to innovative hydropower technologies and a richer understanding of the basin's unique ecology, ensuring a harmonious blend of development and conservation.

6 Conclusion and Recommendations

While driving development, hydroelectric endeavors also prompt significant social and environmental disruptions. Their establishment often results in families' displacement, imperils traditional livelihood means, fractures communal bonds, and compromises environmental integrity. Uprooted communities encounter challenges accessing vital water, electricity, and sanitation services. The once-lived ecosystem, home to various species, undergoes alterations marked by habitat degradation and water source pollution. A noteworthy issue is the limited access that women experience to fundamental necessities like nourishment, healthcare, and shelter post-displacement. Additionally, marginalized groups frequently remain sidelined during compensation efforts.

Through our in-depth exploration of dam construction, we conclude that while dams are instrumental for a nation's economic trajectory, their implications are profound, particularly in regions like the Dhauliganga basin. With its pristine and unique ecosystems, this basin is on the brink of witnessing severe disruptions due to damming and associated hydroelectric projects. Such infrastructural developments are slated to fracture habitats and, over time, erode biodiversity. It's evident from local dissent, which underscores genuine concerns over the area's rich biodiversity and deeply entrenched cultural beliefs.

Mitigation, then, isn't just an option but a necessity. Focused efforts on implementing effective mitigation strategies and rigorous policy adherence are essential. Policymakers ought to prioritize areas with lower ecological sensitivity. It's imperative for the government to stringently apply Environmental Impact Assessment (EIA) regulations, with an emphasis on post-construction management and monitoring of sanctioned projects. This balanced approach ensures progress while safeguarding the region's invaluable natural and cultural heritage.

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