Gupta et al. *Zool. Res. Divers. Conserv.* 2024, 1(X): 1−4
https://doi.org/10.24272/j.issn.2097-3772.2023.008

ZRDC Zoological Research: Diversity and Conservation

PERSPECTIVE Open Access

Dual ecological and socio-cultural fragmentation induced by hydropower dams: case studies from the Greater Himalayan region of India

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Climate change and biodiversity loss are pressing global challenges (Pörtner et al., 2021). However, as global energy demand continues to increase (IEA, 2021), nations face significant challenges to decarbonization and reaching "net zero" due to trade-offs between the often-competing needs of renewable energy generation and biodiversity conservation. For example, hydropower generates renewable energy (Gibson et al., 2017), yet there are well-documented and severe consequences of dam development for biodiversity (e.g., Zarfl et al., 2019) and people (e.g., Bisht, 2009) due to reservoir creation and disruption of river flows. Despite such potentially damaging ecological and social trade-offs, hydropower currently contributes 70% of global renewable energy and there are at least 3 700 large dams planned or under construction globally (Zhang & Gu, 2023).

Dam development in the Greater Himalayan Region of India: a hotspot for biodiversity and cultures

India is the world's most populous and third-largest energy-consuming country, with increasing energy demands largely met by coal, oil, and solid biomass (IEA, 2021), making India the third largest emitter of carbon dioxide after China and the USA. India announced five ambitious targets to achieve "net zero" by 2070 at the 2021 United Nations Conference of the Parties (COP26), including a target of meeting 50% of energy needs using renewable energy by 2030. The Greater Himalayan Region of India has abundant rivers and ideal topography to potentially harness the available natural resources for hydropower generation, with 292 dams proposed for construction (Grumbine & Pandit, 2013). However, existing, and planned dams across the region can prove controversial due to high seismicity, alongside high levels of biodiversity and rich cultural diversity, which can both be negatively impacted by land-use change and displacement (Rana et al., 2007). If the 292 proposed dams are constructed, it has been estimated that 22 angiosperm and 7 vertebrate taxa will be locally extirpated by 2025 due to dam-induced habitat loss and fragmentation (Pandit & Grumbine, 2012). Furthermore, 88% of proposed dams are in subtropical and temperate forests, which are highly vulnerable to species losses driven by land–use change (Grumbine & Pandit, 2013). There is also concern regarding increased human access to habitats via construction roads, which may elevate hunting levels and habitat loss through land clearance (Alamgir et al., 2017). Of particular concern is the relative lack of knowledge regarding the impacts of dams on riverine biodiversity in the region and urgent work is required to plug this knowledge gap.

Dual ecological and socio-cultural fragmentation: case studies from Tehri Dam and Arunachal Pradesh

Much of our understanding of the potentially negative impacts of dam development comes from the environmental literature (Gibson et al., 2017). For example, dam-induced habitat fragmentation has been widely shown to have negative consequences for both aquatic and terrestrial biodiversity across varying spatial and temporal scales (e.g., Benchimol & Peres, 2015; Castello & Macedo, 2016; Hazard et al., 2023; Jones et al., 2016, Xie, 2003; Zhang & Gu, 2023). People and communities can also be permanently displaced through reservoir creation, leading to impacts mirroring aspects of ecological fragmentation through the lens of social and cultural cohesion (Mohanty, 2005).

Here, we explore dual dam-induced ecological and socio-cultural fragmentation in the context of the Greater Himalayan Region in India, a hotspot for biodiversity and human cultures. To illustrate this concept, we use two case studies: (1) Tehri Dam, commissioned in 2006 and (2) the Arunachal Pradesh region, a biodiversity hotspot and location of several indigenous groups with 42 dams billed for construction in the coming decade. Tehri and Arunachal Pradesh differ starkly in terms of vegetation, geological features, biodiversity, and socio-cultural composition, but share similarities in terms of people's livelihoods being intrinsically linked to biodiversity and agricultural activities, and traditional lifestyles and practices enabling co-existence with nature. To illustrate our case studies, we draw on observations from fieldwork in the two case study areas in 2023 and lived experiences across

Received: 07 November 2023; Accepted: 07 December 2023

Foundation items: This work was supported by a UKRI Future Leaders Fellowship awarded to I.J. (MR/T019018/1)

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the region.

Case study 1: Tehri Dam, Uttarakhand: ecological and social fragmentation through nearly 20 years of operation

Tehri Dam, one of the largest dams in the world, is located at the confluence of Bhagirathi and Bhilangna, two tributaries of the river Ganges in the Himalayan state of Uttarakhand, India (Figure 1). Tehri is 260 m high with a 42 km^2 reservoir and storage capacity of 3.5 billion m^3. It provides irrigation to 2 700 km^2 of land in addition to the 6 800 km^2 land irrigated by the two rivers, as well as drinking water to the states of New Delhi and Uttar Pradesh. The Tehri Dam project was planned in three phases:

1. Tehri Hydro Power Plant (Tehri HPP)-1000 MW (4x250 MW). Commissioned in 2006;
2. Koteshwar Hydro Electric Project (Koteshwar HEP)-400 MW (4x100 MW) Commissioned in 2011;
3. Tehri Pumped Storage Plant (Tehri PSP)-1000 MW (4x250 MW) Under Construction.

A total of 135 villages were submerged in the Tehri Dam reservoir, permanently displacing ~100 000 people who were compensated and resettled to different locations (Rehabilitation Policy of Tehri HPP, 1988). Despite the development of a comprehensive rehabilitation programme and compensation policy, certain aspects relating to socio-cultural fragmentation were not explicitly considered (Griffiths et al., 2019). We explore some of those aspects here, with the hope that they will be considered in future dam development policies.

Socio-cultural fragmentation and loss of connection to biodiversity

At Tehri, we observed that women in particular appeared to be impacted by displacement and socio-cultural fragmentation. Displacement severed a deep connection between women and nature, through loss of access to water from natural springs, food and fodder for livestock from the nearby forests, and fresh air. Moreover, social connections to other women—who historically worked collectively to, for example, gather herbs and tend land and animals—were also broken. This social fragmentation resulted in a loss of identity and sense of purpose, as cultures and livelihoods shifted in response to dam construction. More broadly, displacement and rehabilitation of people from the Tehri area to new locations appeared to result in the loss and fragmentation of community bonds, cultures, rituals and traditions, including the loss of cremation sites on the banks of free-flowing rivers, which have religious significance.

People remaining in the region after Tehri Dam was constructed have also been subject to social and cultural fragmentation: the Tehri reservoir created a barrier to human movement across the landscape through the submergence of roads and central markets, which impacted local livelihoods as well as the connection between communities, due to

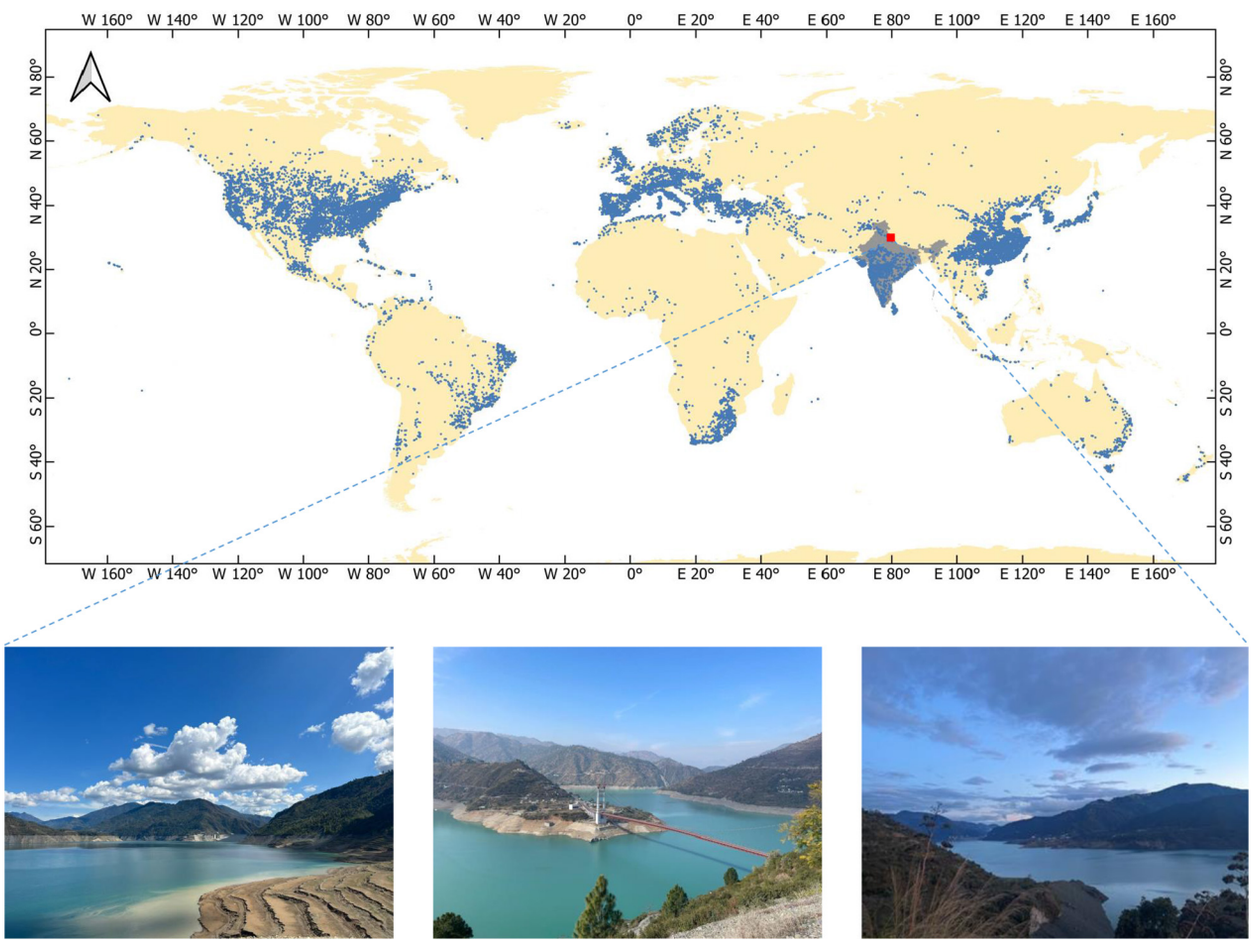

Figure 1 Distribution of dams worldwide (blue points), based on data extracted from the GeoDar dataset: Georeferenced Global Dams and Reservoirs (Wang et al., 2022)

The red point indicates the location of Tehri Dam in Uttarakhand state, India. The photos below are from Tehri Dam taken during the fieldwork from February to April 2023. Photos by Garima Gupta.

significantly increased travel times around the perimeter of the reservoir. Moreover, access to medical facilities and schools was hindered. These factors combined led to the abandonment of agricultural lands and migration to towns and cities away from the Tehri region. The Tehri reservoir therefore contributed to a loss of social and cultural connectivity across the landscape. This connectivity has been partially restored through the construction of a bridge spanning the Tehri reservoir, which opened almost 20 years after the reservoir was filled. However, the legacy effects of social and cultural fragmentation appear to remain, some of which have been more recently incorporated into folk songs and poems involving long-standing negative attitudes towards Tehri Dam from those who have been impacted.

Case study 2: Arunachal Pradesh, a biodiversity and cultural hotspot and a potential hydro-powerhouse

Intersection of biodiversity, indigenous cultures, and hydropower potential

Arunachal Pradesh, located in the northeast of India, is 80% covered by forest and is a biodiversity hotspot and one of 200 globally important ecoregions (Myers et al., 2000; Olson & Dinerstein, 1998). Arunachal Pradesh is also known as the "powerhouse" because of many fast-flowing mountain rivers including tributaries of the Brahmaputra River. The Brahmaputra alone accounts for 30% of the freshwater resources of India and has the potential to produce 44% of India's total hydropower (Zhang, 2016). Thus, the Government of India is pushing for major hydropower projects in Arunachal Pradesh to help achieve "net zero".

Out of the 160 mega projects proposed for Arunachal Pradesh, two of the largest projects—The Etalin Dam (3097 MW) and the Dibang Multipurpose Dam (2880 MW) —are to be built in the Dibang Valley and Lower Dibang Valley respectively, the ancestral homeland to the minority Idu Mishmi tribes (Idu hereafter). Idu are one of the 26 forest-dependent indigenous communities in Arunachal Pradesh and with around 12 000 individuals, they constitute 1.3% of the total population of Arunachal Pradesh (Census of India, 2011). The Dibang Multipurpose Dam has already been approved by the Government of India, after about 15 years of protest and once completed, it will be the largest dam in India. The Etalin Dam still awaits approval from the Forest Advisory Committee (FAC).

The Dibang and lower Dibang Valleys are rich in biodiversity with many Schedule 1 species of the Wildlife Protection Act of India, 1972, including clouded leopards, red pandas, hoolock gibbons, tigers, pheasants and endemic species inhabiting the forests and lands owned or managed by Idu. Many endemic species in the Dibang Valley have been recently discovered (Sheth et al., 2020). Despite high biodiversity levels of regional and global importance, the biodiverse forest habitats of the area are not well-documented in Environmental Impact Assessments (EIA) for the dams (Sheth et al., 2020). Indeed, the number of species listed for the Dibang Valley in the EIA have been underestimated, e.g., the EIA report submitted to the FAC estimated a total of 35 species of orchids in the zone of influence studied, whereas existing studies have documented the number of orchids species to be 117 (Sheth et al., 2020).

Potential ecological and social impacts from dam-induced fragmentation

Given that Arunachal Pradesh is a biodiversity hotspot with high levels of endemicity, there should be a high degree of concern regarding potential impacts from dam construction and consequent impacts to biodiversity in the area (Jones & Bull, 2020). From a socio-cultural perspective, concerns have been raised by local Idu populations who have been protested against the dams since 2008 due to fears that dam development will bring ecological degradation and threaten biodiversity and their traditional culture and practices by dispossessing them from their lands and livelihoods. For example, an important component of Idu culture is the Mithun (*Bos frontalis*), a domesticated bovine species. Mithun is free-ranging and graze on forest lands surrounding Idu villages. Idu communities are concerned that displacement and habitat fragmentation caused by dams will impact the grazing lands of the Mithun, which could result in conflicts with other Idu communities.

Idu are intricately intertwined with the forests ecosystem and livelihoods are heavily dependent on natural resources, and because of their indigenous beliefs and practices, Idu have always lived in harmony with nature, with traditional beliefs and practices governing hunting and human-environment interactions. For example, tigers and hoolock gibbons are considered sacred and hunting of both these animals is strictly prohibited for religious reasons. Idu consider protecting biodiversity as their duty, as they have inherited their forest lands from ancestors and must protect it for future generations.

Since dams are a comparatively recent development in Arunachal Pradesh, much is still unknown about how such major infrastructure projects will impact indigenous people and communities and the biodiversity of Arunachal Pradesh. However, given our existing knowledge on the long-term impacts of ecological fragmentation, and our emerging knowledge of potential socio-cultural fragmentation impacts described here, much more research on social-environmental dimensions of dam development in the region is urgently needed.

SYNTHESIS

Long-term socio-cultural fragmentation an emerging threat alongside biodiversity losses

Both biodiversity and socio-cultural components are potentially threatened by dam development that induces habitat fragmentation and loss of connectivity between communities and between people and nature. Senses of identity, traditional practices, and beliefs that are intrinsically linked to biodiversity and nature appear to be particularly at risk from the dual impacts of ecological and socio-cultural fragmentation.

In order to mitigate some of the risks presented by dam-induced fragmentation effects for biodiversity and people, the more "hidden" impacts associated with socio-cultural fragmentation through space and time should be more fully considered. Environmenatal Impact Assessments must recognise the traditional rights of indigenous communities and potential impacts on cultures and livelihoods. Moreover, all local communities potentially impacted by dam development should be part of the decision-making process when dam construction is proposed. Where dam development is proposed for highly biodiverse areas and biodiversity hotspots, greater weight must be placed on the long-term negative impacts to biodiversity levels from local species extinctions, particularly when endemic species are present.

ACKNOWLEDGEMENT

We sincerely thank the people and local communities surrounding Tehri Dam and the tribes of Arunachal Pradesh for generously giving their time to support our research, for sharing experiences and for helping us understand the wider contexts of dam development from their perspectives. We also sincerely thank Tehri Hydroelectric Development Corporation (THDC) for their warm support for our research in the Tehri area, and for sharing expert knowledge and understanding of dam development in Tehri and more widely across the Greater Himalayan Region.

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