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Hydro Power Development in the Himalayan High Altitude Ecosystems

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ABSTRACT

Mountains always have been a keen investigating area across the world. Supplying half of the world's population with fresh water, they are also considered as "water tower". As the mountains are home to some of the most fragile ecosystem on the planet, adequate environmental and social safeguard is needed while developing energy options in such eco-sensitive regions. In the present developing state of the world's economy, in order to bridge the demand-supply energy gap, there is need for additional energy sources. This gap can be filled by tapping the high velocity rivers suitable for hydro power generation in hilly and mountainous regions. Fortunately, the physiography of India is endowed fast-flowing rivers that cascade down from the parallel ranges of Himalayas having enormous clean and renewable energy potential. But, building hydropower projects have been a tough task due its fragile and geologically active nature. It has been estimated that 70% of India's hydro power potential are in the Indian Himalayan region (IHR). Kinnaur, a Himalayan district has emerged as major hydro production site in recent years, having suitable topography for Run-of-River (RoR) projects. Although on the other hand, developing such projects may have negative impacts on ecological settings of fragile high altitude ecosystem which prevails here. Thus, this paper is an attempt to correlate the development of hydro power projects in high altitude ecosystems in Kinnaur district of Himachal Himalayas. Efforts have been made to map the possible outcome of the hydro installation in sensitive high altitude mountain ecosystem.

KEYWORDS: Hydro-Electric Projects, Mountain Ecosystem, Indian Himalayan Region (IHR), Kinnaur

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INTRODUCTION

Energy requirement is increasing at a rapid rate as the current urbanization pattern is transforming cities into smart cities, thereby increasing their energy demand[1]. India currently generates about 63% of its electricity from thermal power plants and about 24% from hydro-electric projects (HEPs), which are mainly located in the Indian Himalayan region (IHR) [2]. Hydropower is treated as the main source of sustainable and secure energy in high altitude ecosystem. With clean energy mechanism as there is low or negligible greenhouse gas (GHGs) emission when compared to other energy resources, hydro power projects can also be a boon to marginalized mountain communities and downstream population.

Intensive development approach in high altitude ecosystem may have adverse impacts in a long term scenario. Due to the difficult monitoring circumstances there is not only scarcity of long range datasets, but also knowledge of runoff generation in mountain areas. Further limitations are complex topography, vegetation, soils, and rapid spatial and temporal changes in climatic parameters[3]. Development in the mountains, therefore, has to have a different approach considering the fragility and vulnerability of the Himalayan ecosystems. The phenomenon like climate change and associated vulnerabilities can be a major threat to hydro projects in high altitude regions. The hydropower projects are mostly run of the river projects where the river water is diverted through an underground headrace tunnel (HRT) which provides the head for the water to fall through. The fall is used to extract energy by means of turbines located in underground powerhouses deep in the hills. Literature available regarding hydro projects worldwide suggests that there could be cascading effects of several projects within a single river basin as in case of Kinnaur, there are several projects on Satluj and on its major tributaries. Project such as Chango-Yangthang and Yangthnag Khab have been proposed in upper Kinnaur for harnessing the untapped power through river Khab and Satluj in upstream region which falls under seismic zone IV-V.

Hydro power generation in high altitude ecosystems is mainly through reservoir or Run of River (RoR) based systems.

The main sources for selection of sustainability indicators for RoR type hydro projects could be literature review, expert advice, site visits and perception survey. Multipurpose dams are generally located downstream with flat topography as compared to Run of River (RoR) type hydro electric projects which utilize the kinetic energy of the river provided by slope gradient of the region. The upstream and downstream linkages of hydrological processes are complex due to the extreme altitudinal range associated with the young and fragile geology, extreme seasonal and spatial variation in rainfall, and diversity of anthropogenic processes [4]. These linkages are of a critical nature to run-of-river (RoR) type projects in high altitude ecosystems as they govern the power generation process**.**

Recognizing the state's topographical advantage, Himachal Pradesh in 2006 approved a hydropower policy that aims to make the state as the "hydropower state" of India. But on the other side recent report has mapped nearly 292 dams in Himalayan region, which include under construction and proposed sites and pointed out that 54,117 hectares of forests would be submerged and 114,361 hectares would be damaged by these construction activities. This would also result in the extinction of 22 angiosperms and 7 vertebrate taxa by the year 2025; the report was based upon species-area relation model (SAR). Different authors have also provided technique for assessment of hydroelectric power plants in mountainous environment. In the continuation, hydro power projects and community participation needs to be addressed in positive sense in Himachal Himalayas [5, 6, 14].

STUDY AREA

Kinnaur district situated in the easternmost part of Himachal Pradesh is entirely mountainous in nature except few small and deep valleys in between. The district lies between 31° 06' & 32° 06' N latitudes and 77° 45'& 79° 00' E longitudes and falls in the Survey of India degree-sheet nos. 53I, 53E and 52L (**Fig 1**). The district has a total geographical area of 6401 sq km covering 11.5 % area of the state bounded by Lahaul & Spiti district in the north, Kullu district in the northwest, Shimla district in the southwest, Uttrakhand state in the south and further shares an international border with China (Tibet) in the east. Nichar, Kapla, Sangla, Pooh and Moorang are the five tehsils along with one sub-tehsil namely Hangrang. The districts headquarter, Recong-Peo town comes under Kalpa tehsil. Temperature of July and August at places as Chango, Leo, and Moorang varies from 20° to 22° C and in October is about 10° C. The mean monthly temperature varies from 5° C to 23° C. The marginal shift in the monsoon pattern has been noticed over the period of years. The rainfall pattern shows a decreasing trend as one move from west to east. The average annual rainfall in the district is 816 mm. However, much of the rainfall is received in parts of lower Kinnaur. Upper Kinnaur receives more snowfall than the rainfall.

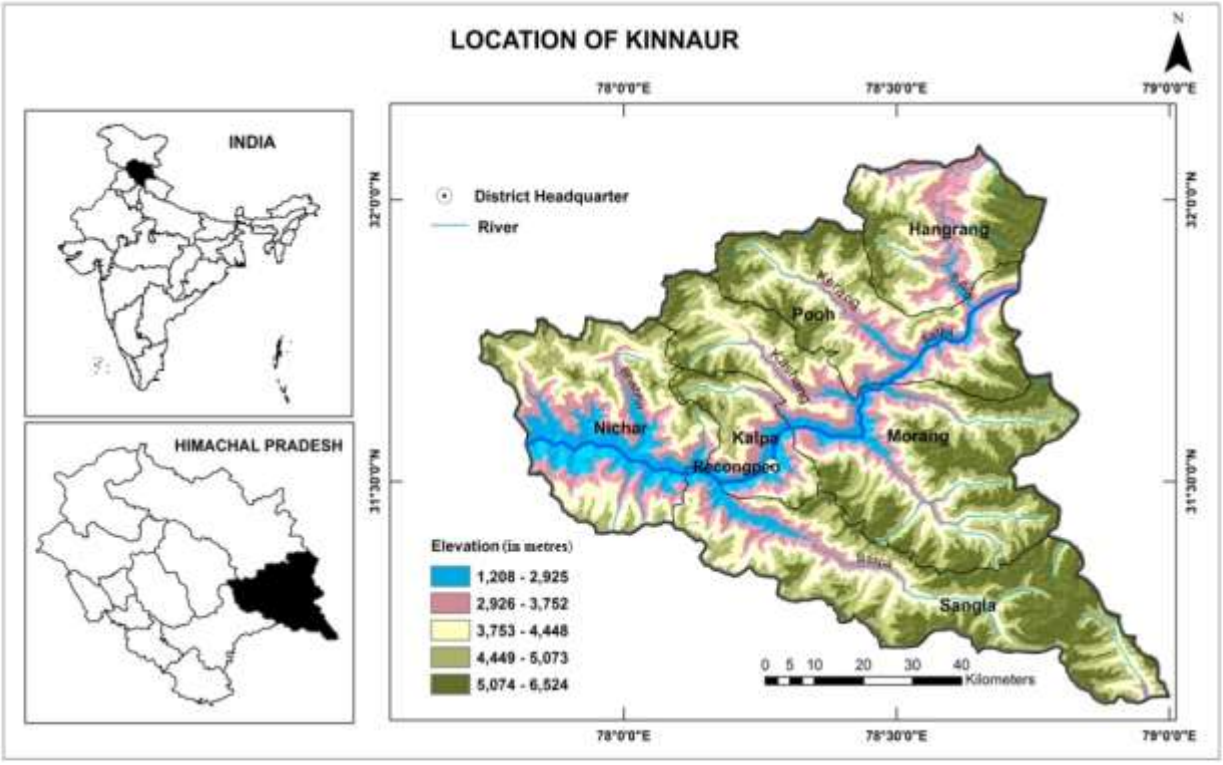

Fig 1: Location of Kinnaur district, Himachal Pradesh

DATABASE AND METHODOLOGY

The present study is based on primary (field survey) as well as secondary data (published articles, literature and government reports). Assistance of geo spatial techniques has been taken to validate the final findings. The secondary data were obtained from the reports of Indian Meteorological Department (IMD), National Hydropower Corporation (NHPC), Himachal Pradesh State Electricity Board (HPSEB), State Census Department and State Government Reports. The elevation of the study area has been mapped by the ASTER data under the environment of ArcGIS 10.5. The buffer zonation method has been used to show the overlapping areas between two projects. GPS coordinates of major landslide sites have been marked on DEM acquired by ASTER from USGS Earth explorer facility. Villages, population, Wildlife sanctuaries along with flora, fauna account in the close ambit of developmental projects have been also been taken into consideration. Due to non availability of some crucial dataset as the IMD stations are functional only at Kalpa and Kaza, secondary sources of information from published articles were used to provide an overview of the meteorological conditions.

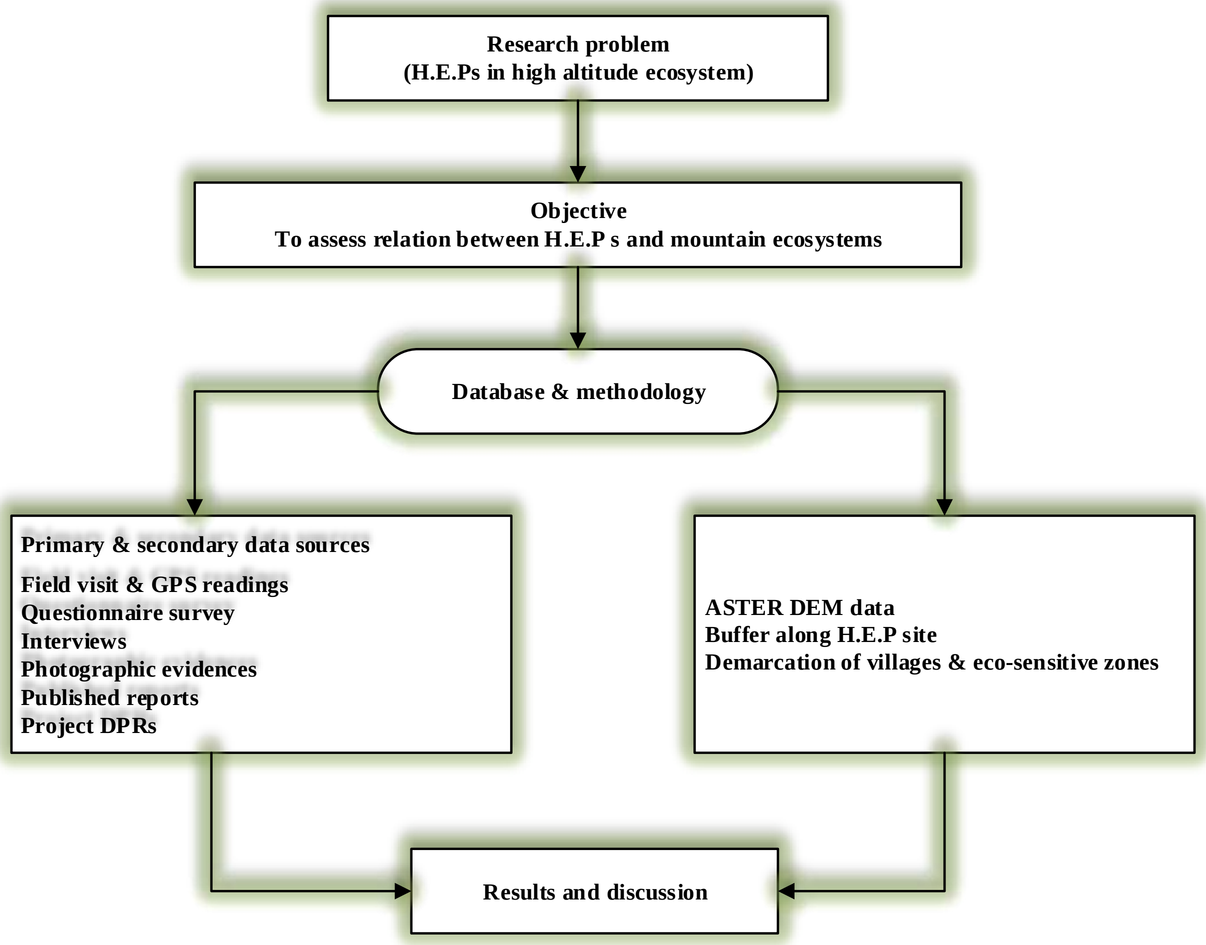

Fig 2: Flowchart defining proceedings

RESULTS AND DISCUSSION

Kinnaur as high altitude ecosystem

The prominent features of mountain environment such as rugged terrain and harsh climate have played a dominant role in influencing the society and adversely impacting the impulses of development. Such mountainous region forms high altitude ecosystems (mountains) which can be better understood with the help of components such as fragility, marginality and accessibility (**Fig. 3**) [7]. Kinnaur being at high altitude ecosystem fulfills these criteria and is prone to several natural and anthropogenic vulnerabilities.

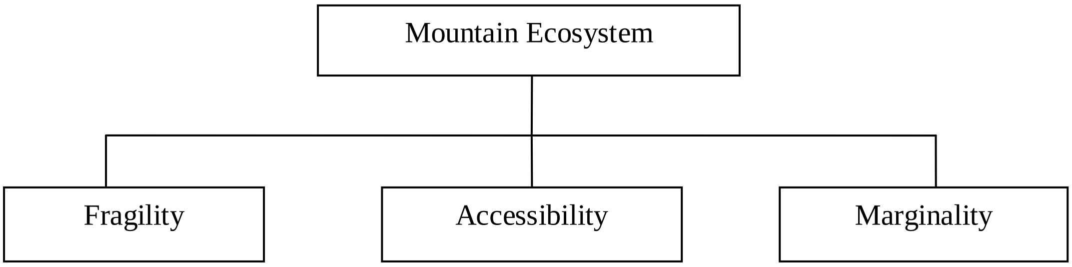

Fig. 3: Components of Mountain ecosystem, Source: N.S Jodha (1992)

Frequent landslides, flashfloods, seismic zones and high erosion rate are some of them, which demarcate Kinnaur as a fragile ecosystem. Lofty mountains along with rugged topography further make the study area inaccessible to some extent as National Highway 22 (NH-22) is the main connecting artery. Tribal population living in harsh climatic conditions of Kinnaur is the marginalized section which is dependent on agriculture/horticulture for their basic needs. Lack of infrastructure further adds to the woes. The natural environment of Kinnaur provides its population numerous ecosystem services which are facing the brunt of climate change and large scale anthropogenic activities in the district. Some of the mountain ecosystem services in the study area can be traced as under:

•Freshwater (e.g. drinking water, irrigation water and water mills)
•Protection from natural hazards
•Resources (e.g. grazing and timber)
•Carbon storage
•Tourism
•Biodiversity

Hydro power development in Kinnaur

The Hydropower development in Himachal Pradesh dates back to pre-independence period (1908), when the king of erstwhile Chamba princely state developed a small project of 0.45 MW capacity. Geographically Kinnaur has been subdivided in fluvial terrain, fluvio-glacial terrain, alpine/ meadows and rocky terrain providing a huge opportunity for hydro power generation through its unique topography and mighty Himalayan rivers. Hydro power development in Kinnaur is mainly along the river Satluj and its tributaries. Over a period of time there has been many fold increase in the hydro power sector in the state (Table 1).

Table 1: Energy Resources of Himachal Pradesh

State	Ownership/sector	Modewise breakup (in MWs)							
		Thermal				Nuclear	Hydro (Renewable)	RES (MNRE)	Grand Total
		Coal	Gas	Diesel	Total				
Himachal Pradesh	State	0.00	0.00	0.00	0.00	0.00	529.60	256.61	786.21
	Private	0.00	0.00	0.00	0.00	0.00	1748.00	542.53	2290.53
	Central	152.02	61.88	0.00	213.90		1288.94	0.00	1536.92
	Sub-total	152.02	61.88	0.00	213.90		3566.54	799.14	4613.66

Source: Himachal Pradesh State Electricity Board Limited, 2015

Ecological setting of Kinnaur

In Kinnaur, there are three parallel mountain ranges, the Zanskar, the Great Himalaya and the Dhaula Dhar with their peaks varying between 5,180- 6,770 m. The altitudinal variation in the district extends upto 1200 - 6500 m. Based on the amount and distribution of precipitation (rainfall and snowfall), the region can be classified into three broad climatic zones: the wet zone (Nichar and Sangla areas), the dry zone (Kalpa and Moorang areas) and the arid zone (Pooh area). As the altitude varies so is the plant and animal species diversity. However, typical topography, severe climatic conditions and high degree of anthropogenic pressure, i.e., construction of a hydroelectric project, collection of fuel, fodder, timber and grazing by the sheep of the nomadic shepherd had resulted in rapid loss of biodiversity.

Flora and fauna

Based on the classification, the vegetation of the region can be classified into 29 types which belong to Himalayan moist and dry temperate forests, sub-alpine forests, dry and moist alpine scrub and meadows [8]. Alpine meadows cover large areas above the tree line (usually above 3300 amsl). Among the agro-ecosystems, besides Chilgoza forest plantations and other agricultural crops, apple orchards constitute a major land use in the study area.

Pinus gerardiana, known as Chilgoza, is a pine that is due to different terrain and harsh climatic conditions prevailing in the area. Many contributions have been made towards the Pteridophytic flora of Kinnaur [9]. Due to high floral diversity, Kinnaur is also well explored for its medicinal and aromatic plants. Wild fauna, like musk deer (Moschus mischiferus) and the snow leopard (Panthera uncia), are under threat partially due to changes in their habitat and the introduction of exotic plant species [10].

Other than abundant floral stock different Kinnaur is also abode to several faunal species which has been recorded in (***Table 2***). The table also gives an account of wild life sanctuaries (WLS) located in the study area along with flora and fauna species found. The buffer zonation method can be utilized for demarcating overlapping boundaries of hydro projects and WLS. As in case of Rupi Bhaba, Lippa Asrang and Raksham- Chitkul, buffer zone of 7 kms (Fig.4) have overlapping areas which have been mapped accordingly.

Table 2: Wildlife sanctuaries with flora-fauna account

Name	**Notified year**	**Area (sq. Km)**	**Altitude (in metres)**	**H.P. in vicinity (10 km buffer)**	**Species found**	
					Fauna	**Flora**
Rupi Bhaba	1982	503.00	909-5650	Ghanvi-I, II, Nathpa Jhakri, SVP-Bhaba, Kut, Sorang, Barakhamba, Himani Chamunda Thingri, Masrang Selti, Roura-II, Nanti, UpperNanti and Wanger Homte)	Serow, Blue Sheep, Red Fox, Musk deer, Goral, Ibex, Leopard, Snow Leopard Brown Bear Himalayan black Bear	Kharsu oak, Alpine pastures , Dry temperate coniferous , Dry broad leaved coniferous
Rakchham-Chhitkul	1962	304.00	32,00-5486	Baspa II	Leopard, blue Sheep, Himalayan black Bear, brown Bear, musk Deer and Goral	Lower western Himalayan temperate, upper western Himalayan temperate, dry broad scru
Lippa Asrang	1962	31.00	4,000-5022	Kashang-I, II, III and IV Masrang Selt	Yak, Ibex, Leopard, Goral, Blue Sheep, Brown Bear, Musk Deer, Himalayan black Beer	Dry alpine scrub, dry coniferous forest, dwarf juniper scrub, western Himalayan temperate forest, dry broad leaved and coniferous forest

Source: Compiled by authors

Table 2 also exhibits the wildlife aspect of Kinnaur district as there are three WLS in the region. As the climatic conditions vary from lower to upper part of the district the influence is seen over species diversity. It has been mentioned earlier that being a part of temperate and cold desert region, there are a variety of floral and faunal species spread over the area. Some of the important vulnerable species are Snow leopard, Musk deer, Bear and Ibex. Although the wildlife is adaptive to harsh and cold climatic conditions of the region, but any further external stress may lead to negative impact on these species.

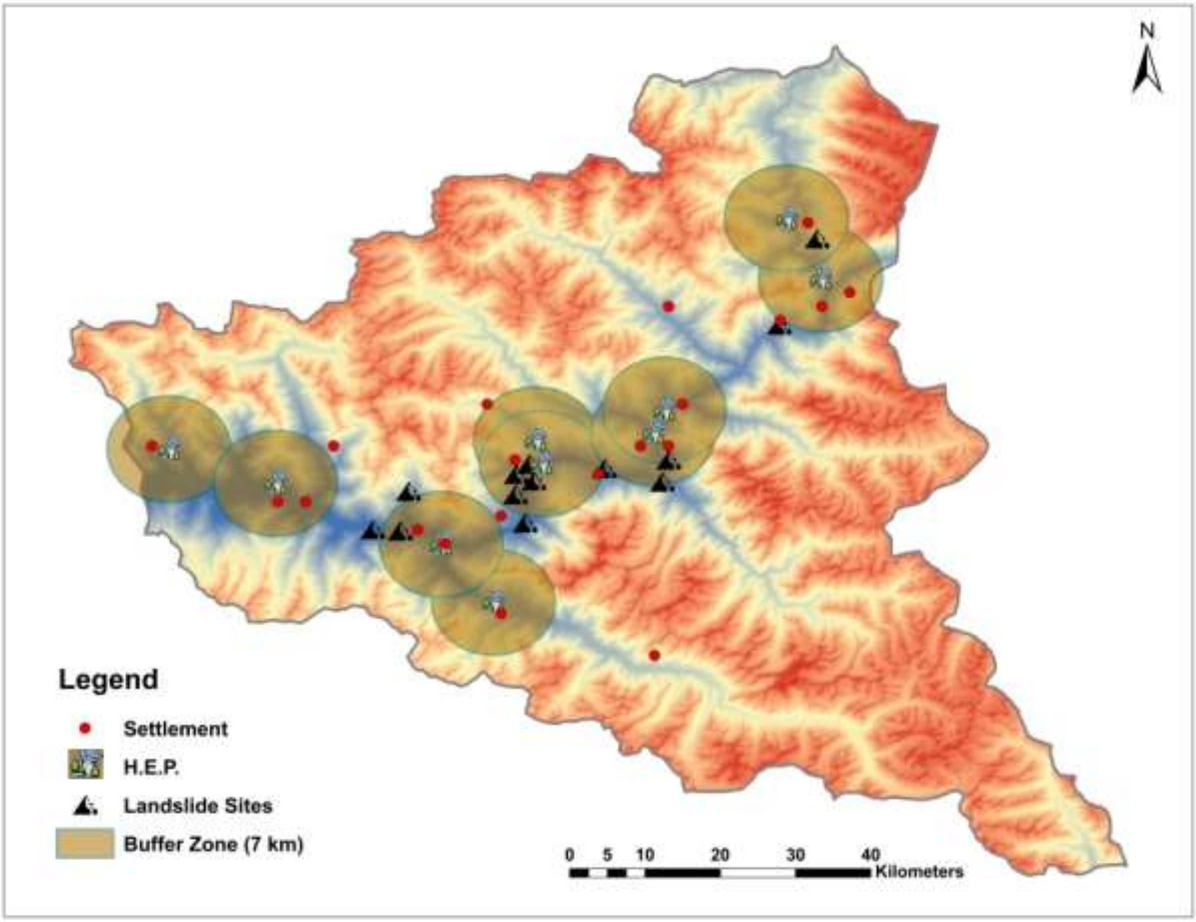

Fig. 4 Buffer zonation along H.E.P sites

Buffer zone of 7 km has been created around each hydro power project site. Literature reviews and committees constituted by the government have suggested a minimum 7 km distance between two consecutive projects. **Fig.4** shows the major hydro power projects in the study area with a circular buffer and thus inference can be made that the overlapping areas may be the most degraded one. **Table 4** defines the buffer zonation; 1 km buffer is the most impacted areas as a major section of the population resides over here. Other than settlement, the forest area is also dominating aspect in this zone. As one moves away from the project area, impact minimizes which can be accessed through a buffer zone of 3-4 km. The number of villages mentioned below is tentative as those have been also incorporated which may have impact of proposed projects in the future.

Table 4: Criterion for Buffer zonation mapping

Parametres	**1 km**	**1-2 kms**	**2-3 kms**	**3-4 kms**	**Total**
No. of villages	97	48	27	26	198
Population	48180	18327	5773	2249	74529
Area (hectares)	24026	8627	10867	6500	50066
Forest(hectares)	1205	741	281	1115	3342

Source: Environics trust, 2014

Detailed account about people's perception on the impacts of hydro-power projects depicts that, as according to project affected people (PAPs) there are striking negative environmental impacts such as water and air, noise pollution along with the turbid river flow [11, 16]. The general observation from the field visit reveals that river stretch upto kilometers remains dry as the water is diverted over long distances through HRT. Landslides have become a frequent phenomenon caused due to blasting of hills which is also damaging forests, roads, houses, water sources and farmland in the villages.

Table 5: H.E.Ps and related activities

Name of the project	Status	Capacity (mw)	Type	Diversion (HRT in km)	No. of trees felled	Forest/agriculture area diverted (hectare)
Nathpa-Jhakri	C	1500	RoR	27.2	10759	147.50
Karcham -Wangtoo	C	1000	RoR	17	11277	496.71
Shongtong-karcham	UC	450	RoR	8	1006	64
Baspa-2	C	300	RoR	7.9	5471	44.17
Bhabha	C	120	RoR	8.4	76	0.98
Sorang	UC	100	RoR	1.5	206	19.17
Tidong-1	UC	60	RoR	8.5	6780	39.04
Kashang-1	UC	66	RoR	2	591	34
Yangthang-khab	P	261	RoR	9	NA	NA
Chango-Yangthang	P	140	RoR	NA	NA	NA
Khab 1	P	450	RoR	12.6	NA	NA
Poo Spiloo	P	NA	RoR	NA	NA	NA
Tidong II	P	NA	RoR	8.25	NA	NA

C= commissioned, UC= under construction, P = proposed, NA= not available, RoR= Run of River, HRT= Head Race Tunnel

Source: Compiled by authors based on various reports

Hydro power and river ecology

The most prominent feature of RoR type hydro power installation is that the whole setup utilizes the kinetic energy of fast flowing rivers supported by the slope gradient of the region. Satluj is the main river flowing through the district. There are several left and right bank tributaries such as Baspa, Tidong, Kashang, creating a dense river network in this high altitude region. The upper Satluj catchment is 19000 sq. km and almost the entire Kinnaur district comes under the catchment area. A major portion of the Sutlej catchment is comprised of steep to very steep high hills of the Greater Himalayas, which remains covered with snow most of the year. But the main issue lies here within as the natural course of the river is altered and is made to flow through tunnels known as Head Race

Tunnel (HRT). Thus the river stretch beyond diversion remains partially dry for kilometers unless the water is thrown back through the tail race to its natural course. The diverted river stretch for different projects has been mentioned in Table 5.

Environmental flows (EFs) are released to ensure that flow in the diverted reach is adequate for the ecological health of the river. EF is a mandatory criterion which needs to be taken into consideration while formulating hydro power development in high altitude ecosystem. Examples can be quoted from primary survey conducted during period of 2015-2016 that there have been adverse impacts of hydro power construction (tunneling, blasting, muck disposal) on the traditional irrigation system which used to be the backbone of agriculture and primary uses in the Himalayas.

Table 6: Hydro power and associated risk in high altitude ecosystem

S.No.	Name	Location	Type of landslide
1	Nathpa landslide	78°08’21’’E & 31°33’45’’N	Translational debris slide
2	Tapri landslide	78°05’47’’E & 31°31’09’’N	Translational debris slide
3	Urni rockfall	78°07’45’’E & 31°30’55’’N	Rockfall
4	Shongtong landslide	78°16’42’’E & 31°31’29’’N	Translational debris slide
5	Powari landslide	78°16΄00’’E & 31°33΄30"N	Complex landslide
6	Telangi Farm House landslide	78°16’03’’E & 31°34’58’’N	Translational debris slide
7	Pangi village landslide	78°17’00’’E & 31°35’42’’N	Translational debris slide
8	Pangi nala landslide	78°17’20’’E & 31°34’30’’N	Translational debris slide
9	Between Morang and Pooh	78°27’00’’E; 31°36’00’’N & 78°34’55’’E; 31°45’40’’N	Debris slide and rockfall
10	Malling landslide	78°37’38’’E & 31°51’51’’N	Complex landslide
11	Khadra Dhang landslide	78°22’21’’E & 31°35’23’’N	Translational debris slide
12	Tirung Khad landslide	78°26’32’’E & 31°34’’25’N	Translational debris slide

Source: Primary survey and state disaster management report, 2014

Horticultural and agricultural activities are also responsible for frequent landslides (Table 6 and Fig. 5) which are mainly due to faulty agricultural practices in the region. The study also observed that in Kinnaur valley, agriculture/horticulture is practiced on steep slopes having thin soil cover where irrigation water acts as a lubricating agent triggering landslide action. The study also recognized that the highway had been widened at the location of the landslide and the steep slope at the location had destabilized the old landslide. Hydropower development provides the society with substantial benefits, but if poorly planned, designed or operated, they can also have serious consequences for the ecological health of rivers and the economic and social well-being of communities dependent upon the goods and services provided by healthy rivers [12].

Plate 1: Landslides in study area, Source: Primary survey, 2015

Limitations to H.E.Ps in high altitude ecosystems

Unstable nature and fragile characteristics of high altitude ecosystem cannot sustain much anthropogenic activities. The fragile ecology coupled with large variations in Physio-climatic conditions contribute to natural hazards in the study area. The major natural disasters or hazards experienced by the region over the years include earthquakes, landslides (Fig.5 & plate 1), flashfloods, cloudburst, avalanches and hailstorms/droughts. The region also falls in seismic zones V and IV.

Since flow is the major driver of ecological processes in rivers, such changes of flow regimes may radically change ecosystems The physical fragmentation of rivers caused by the dams also affects ecological processes and communities[13]. The lack of detailed specific geological/geotechnical investigations for tunnels with high overburden poses a significant risk during project execution. The enormous hydroelectric potential is also partially offset by the hazardous factors of slope instability, high sediment discharge, extremes in flow, and vulnerability of structures to seismic activity. In the high altitude ecosystem, which comprises of relatively young geology, geological and geotechnical investigations are often “superficial” due to the inaccessibility of the project area [15]. Forest Right Act, 2006 is also a major issue in promotion of developmental activities in high altitude ecosystem. The indigenous tribal population is dependent on the forest products for their livelihood, thus any intrusion in the area is a violation of their rights which may result in conflicts with the stakeholders. Limitations also include the cumulative impacts due to series of hydropower construction, operations and allied activities in the same river/ basin as they are more severe and are unaddressed, which may result in vulnerability.

CONCLUSION

Well-planned hydropower projects can contribute to sustainable energy and secure energy. Although mountainous areas are best suited for hydro power generation as the combination of steep slope and fast flowing rivers produces the suitable topographical conditions which have immense power generation potential, but the environmental issues and climate change can pose negatively impact on hydropower generation. These issues need to be addressed in accordance with environmental norms. Shukla committee, 2014 has submitted its report on hydro power projects in Himachal Pradesh and has suggested that there should be no hydro power installation above 7000 feet. The distance between consecutive projects should be as decided by high level committees so that the cascading effect can be minimized. On the other hand, if large-scale development of hydropower in the Himalayas is carefully planned with priority to human development of the area, it can bring a social and economical upliftment of the region. In the difficult and inhospitable terrain of the Himalayas, the development of hydropower on a large scale opens up many issues of social and peripheral economic upliftment along with environmental protection and sustainable development. Promotion of afforestation programmes through plantation of native species such as Chilgoza pine may help in increasing the vegetation cover in the area and could protect this species. Similarly, conservation prioritization of the species, habitats and communities are also required for the management planning of the biodiversity in protected and unprotected areas which all together can decrease the impacts of ongoing developmental projects.

The hydro power installation should adopt plans with the following considerations:

- Prevention of overflow and erosion
- Minimum alteration to natural river ecology
- Minimum intervention in local physical environment and cultural aspects
- Pollution control measures

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