Understanding Climatic Variability and Forest Vulnerability due to Hazards and Anthropogenic Activities: A Study from the Northwestern Himalaya, India

Nidhi Kanwar [1], Jagdish Chandra Kuniyal[1*], Amit Kumar[1] and Shyamal Kumar Nandi[2]

[1]G.B. Pant National Institute of Himalayan Environment and Sustainable, Regional Himachal Centre, Mohal-Kullu-175 126, Himachal Pradesh, India

[2]G.B. Pant National Institute of Himalayan Environment and Sustainable, Kosi-Katarmal- 263 643, Almora, Uttarakhand, India

[*]*Corresponding author's e-mail: jckuniyal@gmail.com*

ABSTRACT

The present study is taken from the two forest divisions- Kinnaur and Rampur of Himachal Pradesh in the northwestern Indian Himalaya. The forests, directly or indirectly, have been the prime sources of livelihood to the mountain communities in the Indian Himalayan Region. The continuous increasing demand with ever increasing anthropogenic pressures in the fragile topography of the Himalaya, impact of disasters can be attributed to higher frequency hydro-meteorological events, related to climate change. These disasters have degraded the existing sparsely distributed forests and related resources making them further vulnerable. Vulnerability analysis, therefore, expresses the relationship between the risks of climate impact and the forest system. Remote Sensing, Geographic Information System, secondary data and field surveys were used to study the climatic variability in terms of temperature and precipitation, prominent existing hazards (i.e. landslides, soil erosion) and anthropogenic activities. It is made clear from the data analysis that overall mean maximum and mean minimum temperatures stood to be 4.19°C and -7.71° C respectively. The mean precipitation (2.04 mm) was recorded from 1979 to 2013 during a period of 34 years. The standard deviations calculated were 1.14 for maximum temperature, 1.33 for minimum temperature and 0.52 for precipitation. The results of the climatic parameters (maximum and minimum temperature, precipitation) have shown an increasing trend. If such variability in climate parameters continues to widen, the prevailing geo-hazards with continuous anthropogenic pressures in these fragile regions will keep on increasing causing a great damage and loss to the existing forest resources. The results also showed that total 57.73 km^2 area got affected and turned to vulnerable due to landslides and soil erosion occurrences among forest and non-forest land use and land cover classes. Therefore, there is a need to follow strictly the norms of sustainable development to go for any of the economic activity in the mountain scenario to reduce the climatic and forest vulnerability.

Keywords: *Climatic variability; Forest vulnerability; Hazards; Anthropogenic pressure; Sustainable development; Indian Himalaya.*

INTRODUCTION

The ecosystems which are most vulnerable to the climate change are the high mountain areas (Beniston, 2003; Bhutiyani, *et al*., 2010; Singh *et al*., 2010). The changing climate and warming of the atmosphere has a large impact on water resources, agriculture and the overall economy of the country (Shekhar *et al*., 2010). Climate change has also its impact on the

Himalayan forests resulting in a change in the forest community structures (Negi, 2009). So, it is necessary to study different aspects of climate change, based on the available long-term data over the region. Understanding local peoples' perception in terms of climate change have been one of the fundamental issues to address the upcoming challenges on the way of the issues related to land and forest conservation.

Vulnerability is a multidimensional (i.e. physical, social, economic, environmental, institutional, and human), dynamic (changes over a time), scale-dependent (from individuals to countries) and site-specific (each location might need its own approach) (Bankoff, 2003). Vulnerability analysis, therefore, expresses the relationship between the risks of climate impact and the system. A system is regarded as vulnerable if the climatic impact is high and the adaptability of the system is low (UNDP, 2005). Globally, forest cover comprises of 31% of the total earth's land surface (Keenan *et al*., 2015). India's National Forest Policy (NFP) of 1988 aims at maintaining 66% of the total geographical area in the hills under forests (Negi, 2009; HPFD, 2017). The Indian Himalayan Region (IHR) has nearly 42% of its geographical area under forests, that represents one third of the total forest cover in India and nearly half (47%) of the very good forest cover of the country. The forest cover in Himachal Pradesh constitutes 4.80% of the India's total forests (FSI, 2013). The Himalaya as an important ecosystem service with its vast green cover, acts as a 'sink' for carbon dioxide (Singh, 2006). The forest of Himachal Pradesh is known just like a green pearl for its grandeur and majestic view of the Himalayan crown (HPFD, 2017). This life supporting system is presently under great stress due to impact of haphazard developmental activities, and related natural and man-made hazards. The forests of Himachal Pradesh are rich in vascular flora, which form the conspicuous vegetation cover. Forests have a great importance from physical, social, and environmental point of views. Forest vulnerability assessment is incomplete without the study of the forest community of a particular area. Forest vulnerability has become a major concern due to increasing anthropogenic pressure, changing human traditions, socio-economic activities and climate change threats at local, regional and global levels. The specific drive of this study is to make understanding about the climatic variability during a long period of time and to assess the impact of prevailing hazards (specifically landslide and soil erosion) and anthropogenic activities making the sparse forests vulnerable of the study area through the perception of forest-based communities in the selected villages in the Kinnaur and Rampur forest divisions. The study also incorporated the secondary information and different applications of Remote Sensing and Geographic Information System (RS &GIS).

STUDY AREA

Prior to the independence of Himachal Pradesh state, the Kinnaur valley was a part of Bushahr state which had its Headquarters at Rampur. The present study area comprises of mainly two forest divisions of Himachal Pradesh. One is the Kinnaur forest division and other is Rampur forest division, both come under Rampur forest circle. The extent of the study area lies between 31º15'50" N and

32º05'20" N latitudes and 77º 30' 0" E and 79º 00'50"E longitudes (Fig.1).

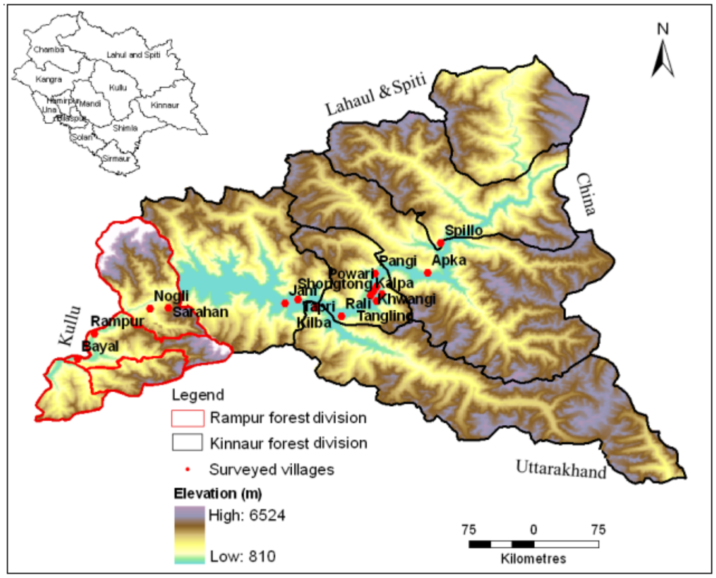


Fig.1. Study locations within Himachal Pradesh, India

The geology and rock affect the vegetation of a place by influencing mainly moisture regime, soil, texture and drainage. In the areas, having adequate forest cover especially of Deodar (*Cedrus deodara*), Kail (*Pinus wallichiana*), Silver Fir (*Abies pindrow*) and Spruce *(Picea smithiana),* the soils are generally deep to very deep. In Deodar and Kail forests, the soil has adequate organic matter whereas in Fir and Spruce forests, humus layer is relatively thick. However, soil in Chil (*Pinus roxburghii*) forests is poor in terms of organic matter due to repeated fires and thus is vulnerable to soil erosion. Oak forests are generally accompanied by matured soils of adequate depth and possess high water holding capacity with acidic in reaction. The profile is well developed in higher locations under forests. Lower downslope region suffers from erosion and has no further scope to develop. Soil over most of the areas is formed *in situ* and is, more or less, loam to clay loam. Generally, on the ridges, spur, slopes and southern slopes have a shallow soil. On the other hand, it is moderately deep on the cooler aspect and gentler slope. The climate is temperate but due to variation in altitude, the tropical climate is found to be in sub-mountainous areas at the base of the Satluj valley to alpine in the upper reaches. Semi-Arctic conditions prevail in some patches of the region. Months from March to April and October to November are cool and bright. This tract is endowed with three distinct seasons, viz; summer, rainy and winter. The rain starts during the summer in the last week of June and extends up to September. Snowfall starts from November and lasts by the end of March on higher altitudes.

MATERIALS AND METHODS

The main objective of the study is to understand the climatic variability in terms of temperature and precipitation along with the forest losses and its vulnerability due to the impact of landslides, soil erosion and others. Human intervention study was also part of the study which, directly or indirectly, affects the forest resources. During the study both primary and secondary data were collected from different sources. Primary data were collected through participatory approach, questionnaire survey, and intensive field observation. Preliminary survey was also done to know the status of climatic variability and major anthropogenic activities taking place in the study area. Under peoples' participatory approach – a questionnaire survey in 12 villages in the study area (Kinnaur & Rampur forest divisions) was conducted. These villages from highest to lowest altitude were: Kwangi (2972 m), Apka (2454 m), Tapri (2385 m), Spilo (2347 m), Tangling (2211 m), and Powari (2044 m) in Kinnaur forest division, and Sarahan (2219 m), Sainj (1679 m), Nogli (1361 m), Rampur (1180 m), Bayal (1103 m), and Luhri (835 m) in Rampur forest division. The random samplings were done in the selected villages. The villages which were near the forests and were directly or indirectly depend on forest resources and also affected due to hydroelectric projects (HEPs) selected. The questionnaire survey, group discussion, and personal observations were done. Daily data of Climate Forecast System Reanalysis (CFSR) were used due to limited availability of other data source. These were procured from Global weather data for SWAT which was available for the period of 1979-2013 respectively. Based on these data sets, the distribution of maximum, minimum and precipitation amount were determined. For hazard analysis, the study area was demarcated; then the satellite images were acquired from the USGS. The visual interpretation and digitization of the affected areas due to mass movement (landslides) and soil erosion were identified under ArcGIS and Quantum GIS. Thereafter, data of the forest cover were collected from the NRSC for land use and land cover data for 2014 (Resolution 23 m) and Landsat ETM+ (30 m). The forest cover was extracted and this layer was overlaid on the satellite images (Landsat). After that, the removed areas of forest cover were counted. At the same time, a field survey was done to identify some locations of landslides as well as soil erosion incidences in the study area. GPS locations and overlay analysis on the satellite images were taken into account to find the degraded areas. However, locational or track mapping has limitation because it was not possible to pinpoint all locations falling within the study area because of undulating topography. The help of digital globe was also taken for better interpretation or visualization (resolution 0.5 m Google). The vulnerable area under the soil erosion, and landslide were identified. For this purpose, forest areas above 30º with high steep slope were selected. Afterwards, forest layers were demarcated and overlaid on the secondarily generated maps of soil texture / soil types and lithology. Slope map was generated through Digital Elevation Model (DEM) with 30 m resolution. Finally, the forest affected areas were extracted falling under the high slope and loss due to unconsolidated type of soil texture and lithology. Then, the area was manually extracted and computed. All the data were analyzed in Geographic Information System (GIS) and statistics' environment. However, it was the part of vulnerability assessment study, so this assessment demanded extensive field surveys; GIS, GPS, Remote Sensing, questionnaire surveys and then qualitative assessment (Fig.2). The common absolute measure to test variability within variables or indicators is the standard deviation (Hamid *et al.*, 2014; Wani *et al.*, 2017). Standard deviation explains how measurements for a group are spread out from the average or mean value. Low standard deviation indicates that most of the numbers are very close to the average; while a high standard deviation shows the numbers are spread out.

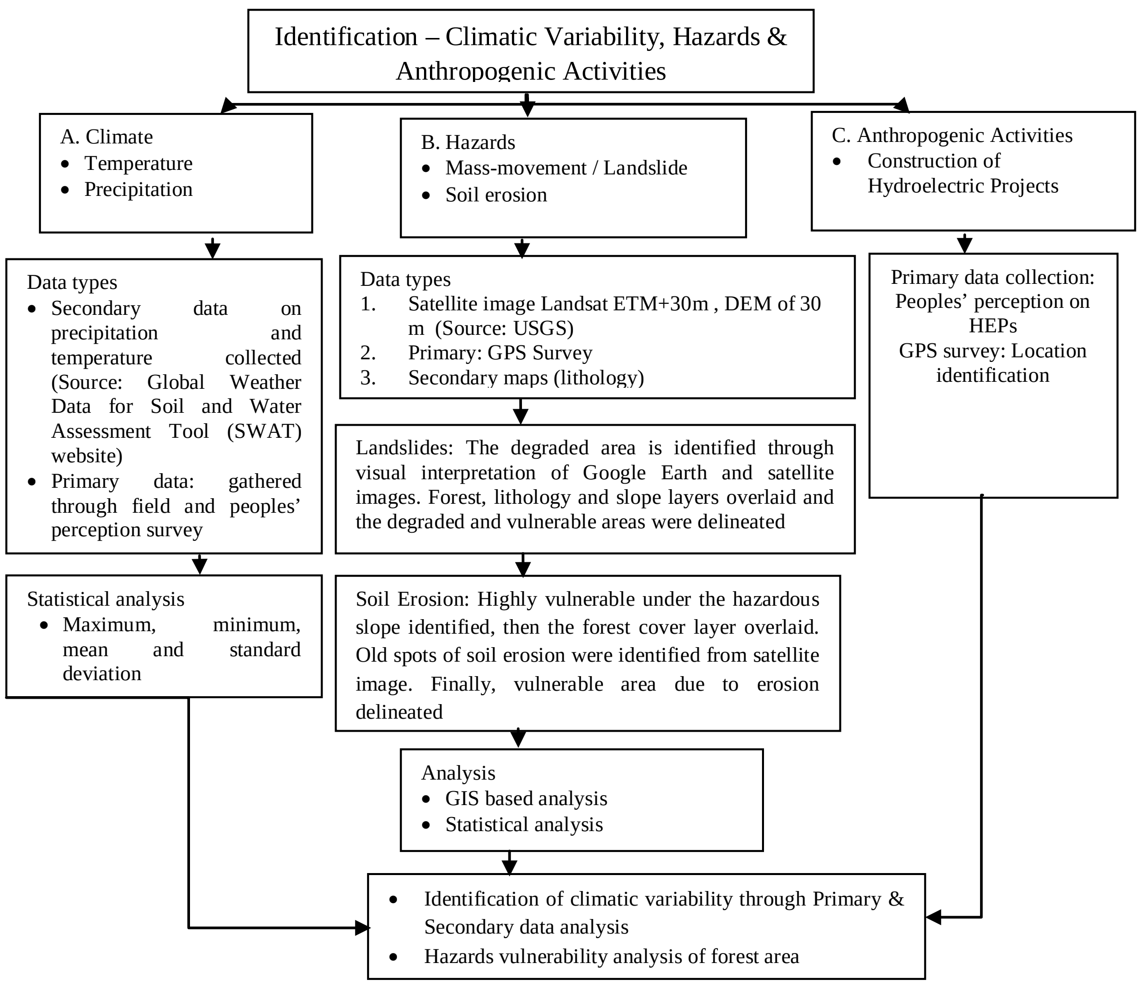
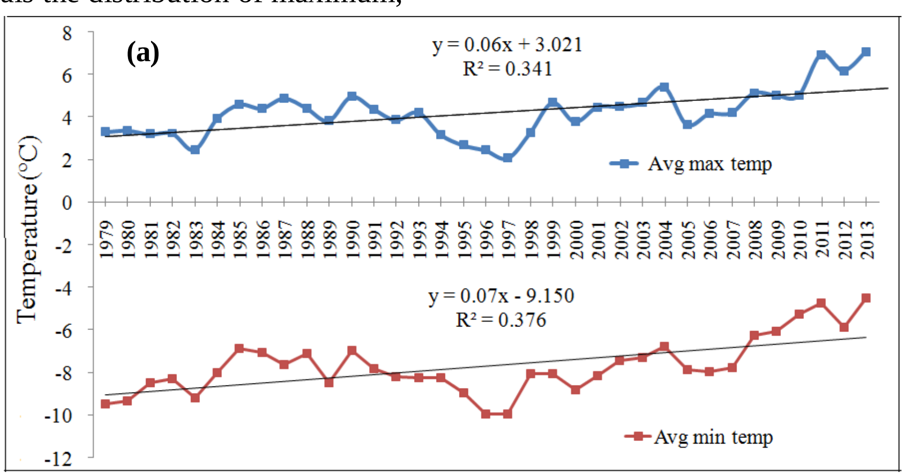


Fig.2. Methodological approach- data, tools and methods

RESULTS AND DISCUSSION

i. Climatic variability

From the perception survey, it was found that 80% of the total respondents were aware of the climate change and its impacts on their surrounding environment. While 72% respondents of the total perceived that 'weather pattern' is changing in terms of temperature, rainfall, moisture, etc. Climate and its variability have wreaked havoc on agricultural system in the mid-hills of Himachal Pradesh especially due to uneven distribution of rains (Bhardwaj *et al*., 2010). It is likely that changing temperature and precipitation pattern will produce a strong direct impact on both natural and modified forests. A number of biogeographical models demonstrate a polarward shift of potential vegetation for the $2XCO_2$ climate by 500 km or more for boreal zones (Kirilenko and Sedjo, 2007). About 66% of the total respondents also felt that snowfed areas are now converting into rainfed zones. Temperature and precipitation variability are the most sensitive indicators of climate change. Figure 3 (a & b) reveals the distribution of maximum, minimum temperatures and precipitation from 1979 to 2013 for the study area. It is made clear from the data analysis that overall maximum temperature was recorded highest (7.0°C) in 2013 and lowest (2.1°C) in 1997. The overall mean maximum temperature (4.19°C) was recorded from 1979 to 2013. The highest minimum temperature was recorded -9.97°C in 1996 followed by -4.52° C in 2013; while the overall mean minimum temperature stood to be -7.71°C (see Fig.3a).The maximum precipitation of 3.04 mm was recorded in 2010 and minimum of 1.11 mm in 1987 (see Fig.3b). The mean precipitation (2.04 mm) was recorded from 1979 to 2013.The data show increasing trend regarding climatic indicators. The highest standard deviation for minimum temperature was 1.33 followed by 1.14 maximum temperature and 0.52 precipitation. The Western Himalaya recorded an increase of 0.9° C maximum temperature over 102 years (1901-2003) (Dash *et al*., 2007). The variable nature of rain has its adverse impacts on crops (see Fig.3b).



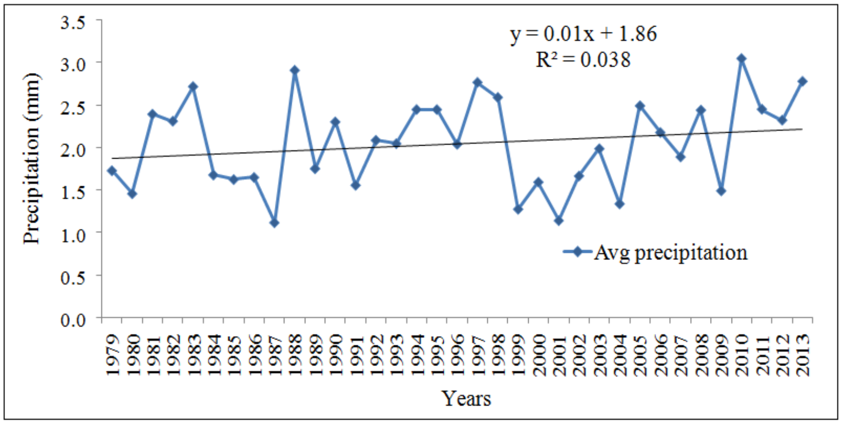


Fig.3. Trend of climate indicators at Kinnaur and Rampur forest divisions: (a) average maximum and minimum temperature, and (b) average precipitation

Increasing precipitation in the study area is also responsible for the incidences of mass movement and soil erosion (see Fig.3 & Fig.4).

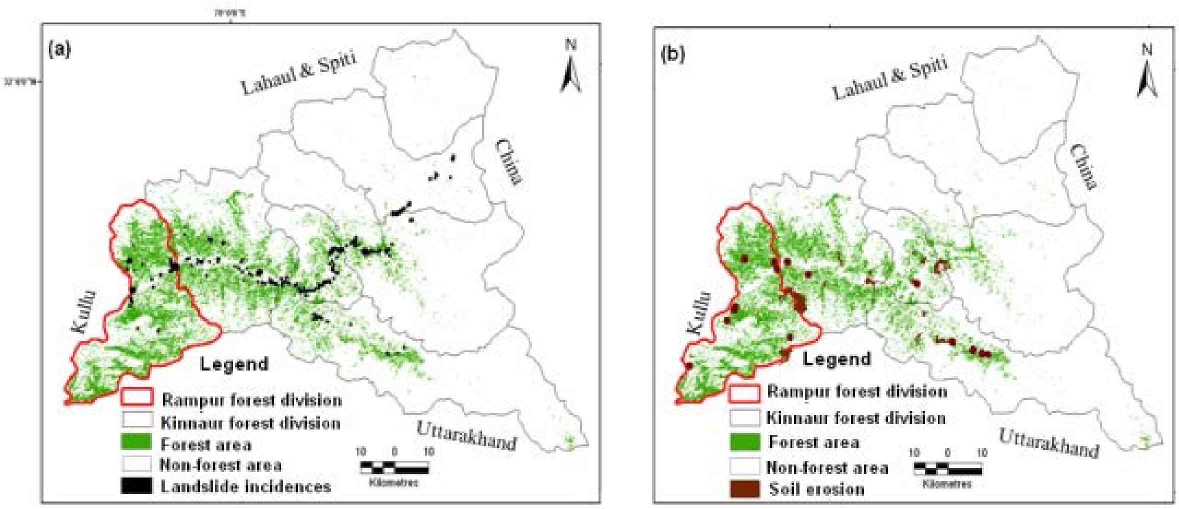


Fig.4. A state of forest resources: (a) forest degradation due to landslides, and (b) forest vulnerability due to soil erosion

People's perception explained different biological parameters like lack of chilling hours, dry tree growth, and shifting of vegetation (Table 1). In snowfall area, 60% of the total people believed that chilling hours for fruit formation such as apple, apricot and chilgoza nuts (*Pinus gerardiana)* were reduced as compared to the previous years. Prolonged delay in cold temperature conditions in December and January severely affects the chilling requirement (Gautam *et al.*, 2014). Dry tree growth period was highly observed in the Rampur forest division. According to the peoples' perception, seasonality in terms of flowering and cycles of apple fruiting has been affected as compared to the previous years. During the group discussion with the villagers, it is made clear that indications of climate change is highly noticed in terms of increasing temperature and rainfall which has adverse impacts on the physical landscape of the region.

Table 1. Peoples' perception survey (n=51)[a]

Sr. No.	Peoples' perception	Yes	No	% responses
1.	Peoples' awareness regarding their surrounding environment & climate change	41	10	80.39
2.	Changing weather pattern in the region	37	14	72.54
3.	Changing snow fed areas into rain fed areas	34	17	66.66
4.	Forest loss due to landslides	31	20	60.78
5.	Status of soil erosion problem	36	15	70.58
6.	Adverse impacts due to construction activities / loss of forest	35	16	68.62
7.	Reducing chilling hours in the region	31	20	60.78

[a]*Indicates number of respondents taken into account under the perception survey*

ii. Hazards

Based on field's observation, the respondents believe that 'landslide' is a major hazard in the region. It is responsible for the maximum disasters to the forest and human resources. Increased run-off is triggering incidences of 'landslides' in the villages under study. The respondents under survey told that the events of floods have also been increasing from the last few decades. They also mentioned that due to multiple impacts of climate change and anthropogenic activities, these are degrading the morphology of River Satluj. It is made clear from the visual interpretation of satellite data that the Kinnaur forest division has witnessed about 3.09 km^2 forest area and 10.04 km^2 under non-forest being severely affected by landslides along the Satluj valley particularly from Khab to Rampur (see Fig.4), as well as along the Sangla valley (Fig. 5). While at Rampur division, least area with 0.22 km^2 was affected under forest but most area with 0.64 km^2 under non-forest. Slopes which are not vulnerable and classified from 0-30^o have minimum physical loss. Vulnerable slope Upon querying, one of the senior citizen told, 'I had never seen drying up of traditional water sources throughout the year, but these days water availability to us has become scarce and seasonal'. categories include the slope of >30^o which have high physical loss in terms of soil erosion and landslides. Most of the forest loss 49.94% (28.83 km^2) was observed under the vulnerable slope (>30) category. The lithology map was prepared on the basis of geological map (Sheet No.1) of the north-western Himalaya. This was generalized and modified after preparing the geological map of the Himalaya on 1:1 scale Plate-1 by Geological Survey of India, Government of India (GSI, 1989). The study area has P_{t23} lithology (slate, phyllite, quartzite, grey shale, siltstone, limestone, gypsum, metamorphosed in proximity of granite (Shimla group / Jaunsar group), Y (granite & granitoid complex-igneous rocks), P_{t1} (regionally metamorphosed katazonal meta sediments), P_{t3e} (greenish grey sandstone, quartzite, grey & dark shale sandstone, band of limestone, phosphorite) and OC granite and granitoid complex (igneous rocks; Fig.6).The affected area under the forest was recorded under the lithology types of P_{t23} (1.29 km^2), Y (4.24 km^2), P_{t1} (5.8 km^2) and at Rampur Y (1.8 km^2). The total affected area due to hazards was observed as 13.13 km^2. GIS analysis showed that total 57.73 km^2 area got affected and become vulnerable due to landslides and soil erosion (see Figs. 4, 5 & 6; Table 2). Tremendous amount or erosion occur on the banks of river, streams and agricultural fields and settlements due to flash floods in the monsoon (Rawat *et al*., 2012). The fragility of these mountains was highlighted in the 15th to 17th June 2013 when unprecedented amount of rain and snow triggered landslides, erosion and flash floods affecting 2500 crores of infrastructure properties (IWP, 2017). It caused loss of property and damaged apple crop worth for hundreds of cores of rupees. Soil erosion was also highly noticed in the area where construction activity, like construction of Shongtong-Karcham HEP in Powari area is still in progress. Sustainable management of forests is essential for the management of hydrological hazards such as floods, erosion and landslides in both monsoon as well as in non-monsoon periods (Rawat, 2012).

Fig.5. Forest degradation near Sangla valley due to landslides (left) and soil erosion (right)

Table 2. Affected area (km^2) due to different hazards

Sr. No	Land use classes	Area affected due to landslides		Area affected due to soil erosion		Total
		Kinnaur division	Rampur division	Kinnaur division	Rampur division	
1.	Forest	3.09	0.22	22.26	3.26	28.83 (49.94)
2.	Non-forest (forest, built up, agriculture, grassland, wasteland, scrubland, water bodies)	10.04	0.64	14.25	3.97	28.90 (50.06)
	Total	13.13 (22.74)	0.86(1.49)	36.51 (63.24)	7.23 (12.52)	57.73 (100)

Values in parentheses are in per cent

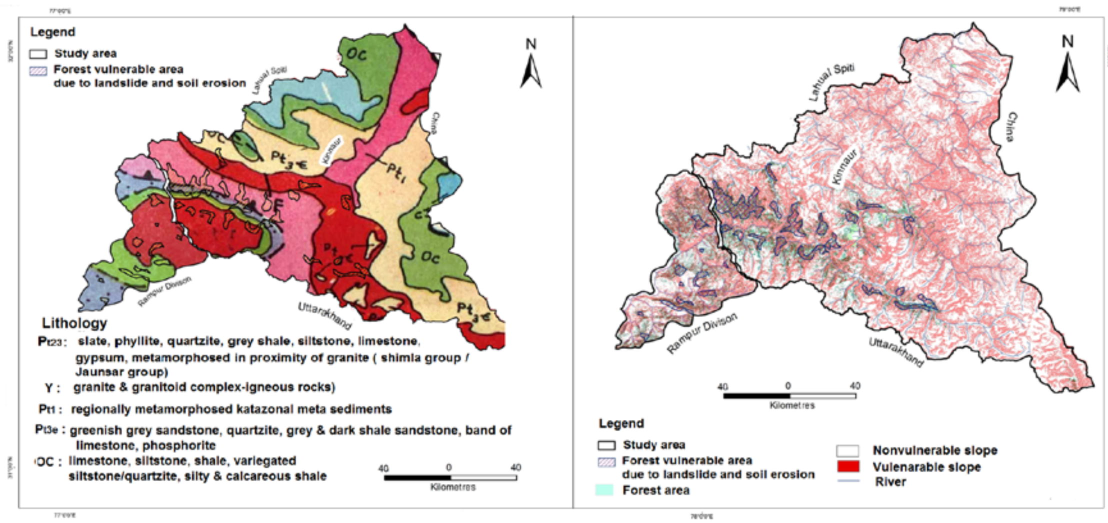


Fig.6. Lithology and slope maps in the study area (*Source: Geological map of the Himalaya (1:1 scale), Plate-1 by Geological Survey of India, Government of India; 1989*)

iii. Anthropogenic indicators

The power sector has emerged as a big contributor to economy in Himachal Pradesh. The state has the second highest potential for hydro energy in the country estimated to be around 27,433 MW (IWP, 2017). About 30 large and small hydropower projects have been planned to produce more than 5,000 MW in just Kinnaur on the River Satluj (IWP, 2017). Respondents have highlighted anthropogenic pressure in the forest division of Kinnaur. They also mentioned that hydropower projects are itself vulnerable to 'climate change'. But at local level, introducing hydropower projects may have economic benefits. However, in a haphazard manner, development of HEPs in this river basin has continuously been degrading the physical environment (Fig.7).

Fig. 7. Land degradation (left) and trees loss (right) during field study near tunnel site of Tidong- I (100 MW) project site

The 68% individuals of the total surveyed people believe that the loss of forest is very common during the hydropower construction activities (Table 2). In case of 1000 MW Karchham-Wangtoo hydropower project, 17 km long tunnel passing (IWP, 2017) beneath the six villages would affect water aquifers and would dry up of the natural springs. The newly introduced apples in Kinnaur are well-known for their natural sweetness. 'Because of continuous construction activity, huge amount of dust settles down on the orchards hampering flowering and growth of apples,' says respondents from the Shongtong village. If alike developmental activities in the Himalayan region are not properly taken care of, it may pose heavy ecological threats to delicate flora and sensitive fauna. With a view to minimize adverse impacts and to make the hydroelectric power projects ecologically sustainable and economically profitable, aerial inter-distance between the two projects at a site need to be determined with 7 km radius for large (above 25 MW), 5 km for medium (5 - 25 MW) and 3 km (below 5 km) for small projects in the mountain environment (Kuniyal *et al*., 2015; Kuniyal *et al*., 2017). The drought and flood will not only affect the future of the hydropower projects, but will also the sparsely distributed forest resources (Sharma *et al*., 2017). As a result, areas located in the lower basin of the River Satluj from Khab to Kol Dam are more vulnerable to climate change. Respondents from Spillo village perceive that water availability to the residents have reduced to 66% of the total supply. These areas are also susceptible to 'pollution' as economic activities are growing and water flow is declining. This change would have significant impacts on human and river ecosystems. Respondents during field visit made clear that developmental interventions have the adverse impacts mainly on river morphology, river channel, forest cover and natural hazards. Respondents from Bayal, and Nogli villages perceive that ground water quality is also deteriorated.

CONCLUSION

The Himalayan mountains have been highly prone to several geo-hydrological hazards. Forest losses in terms of its area 25.83 km^2 (44.74%) were recorded due to the impact of landslides and soil erosion in the study area. The study area has witnessed a lot of developmental changes during the last twenty six years, *i.e.*, between 1990 and 2016. Dam construction for hydropower development without a carrying capacity and a strategic planning of a basin is one of the major haphazard developmental activities, which is responsible reasonably for deforestation. It is made clear that about 3.09 km^2 area of forest in Kinnaur forest division was damaged due to landslides from Khab to Rampur in the Satluj valley. While in Rampur forest division, smaller area about 0.22 km^2 of forest was damaged due to landslides. Hydropower projects on the fragile topography fall under the fifth seismic zone and might have worst forms in coming future in the region. The result of climatic parameters clearly indicates changes occurring in the temperature and precipitation patterns in the study area. However, the loss of forests can be prevented and controlled due to a practice of only sustainable development of hydropower projects. It is because of slope failure and soil erosion that might have more fragility commonly prevailing in this region.

Landslides and soil erosion are highly responsible physical determinants in making stabilize the physical environment in this region. These two factors are, therefore, responsible for the forest losses triggered further by climatic variability and unsystematic, and uncontrolled human activities. There is a need for sustainable development and extensive study to reduce the climatic and forest vulnerability in the study area. To reduce disaster losses, more efforts should be done on Disaster Risk Management, with a focus on hazard assessment, elements-at-risk mapping, vulnerability assessment and risk assessment, which all have an important spatial component.

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