

# Climate change impacts on glacier-fed and non-glacier-fed ecosystems of the Indian Himalayan Region: people's perception and adaptive strategies

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**Mountains are considered as the early indicators of climate change. The study aims to understand how the Himalayan communities perceive climate change, and how this change has impacted the livelihood and sustenance of local people particularly in the remote and rural areas of the region. In view of this, 994 households of 25 villages were interviewed from five basins (five villages per basin) of the Indian Himalayan Region. Their perceptions mainly of climate change were validated/compared with the available climatic indices. People perceived rainfall pattern to be less predictable, greater change in land-use pattern, adverse impacts on forests and human health and overall reduction in their harvests. Seasonal increase in temperature was also reported. Capacity-building programmes for the inhabitants, including the most vulnerable communities in the wake of climate change would be significantly fruitful by way of mitigation and adaptation strategies.**

**Keywords:** Adaptive strategies, climate change, glacier-fed and non-glacier-fed ecosystems, people's perception.

## Introduction

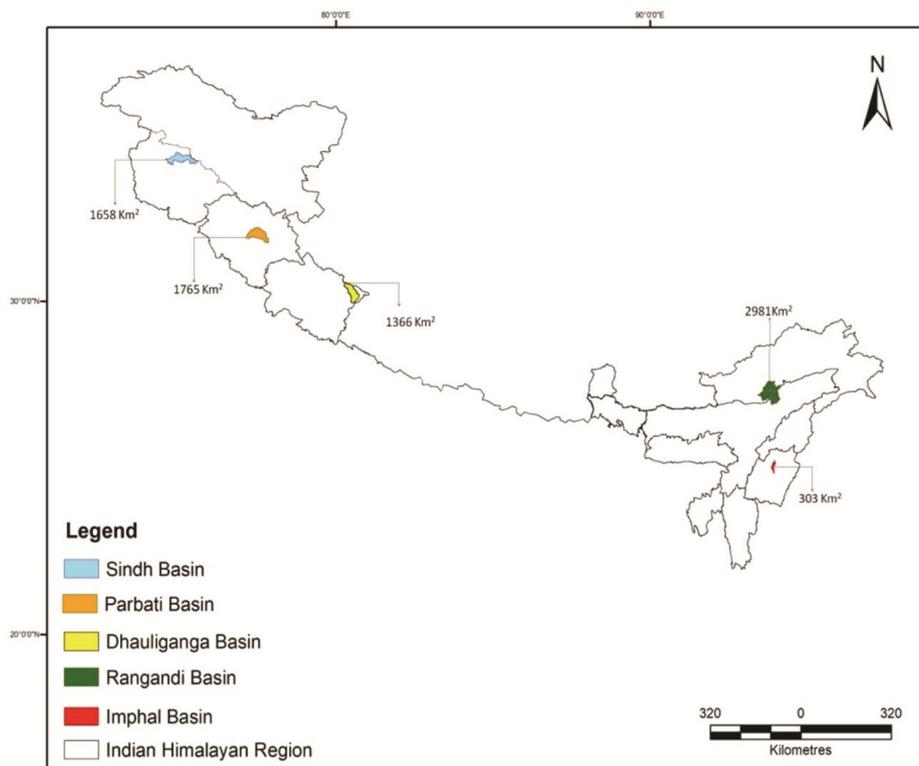
CLIMATE change is a major challenge being faced by the world mountains, including the Himalayan region which shows a clear-cut indication in many areas<sup>1</sup>. It is considered as a significant threat to rural communities that are more dependent on natural resources. Especially in developing countries, the impacts are more severe, but those residing in high-risk regions in developed countries are also

greatly impacted<sup>2,3</sup>. For developing nations such as India, where agriculture continues to be the backbone to support livelihood options for more than two-thirds of the population, a study of the nature and impact of climate change on agriculture and people's livelihood is of greater importance<sup>4</sup>. Changes in temperature and precipitation patterns and their impacts on water resources, glaciers, ecology, agriculture, etc. are being attributed to changing climate over the Himalaya<sup>5,6</sup>. Temperature is showing an increasing trend in the Western Himalaya, while precipitation is showing a decreasing trend during winter and summer periods<sup>7-9</sup>. Receding of glaciers and upward movement of snowlines affect river-water discharge and volume in the downslope region. This change in water flow may lead to a variety of social issues, and would adversely affect hydropower energy generation, existing biodiversity and agriculture-based livelihood options<sup>1</sup>.

For centuries indigenous communities have witnessed local changes in climatic conditions in their surroundings. They have a rich experience with their ecosystem's natural rhythms and processes<sup>10</sup>. Concurrence between scientifically documented facts and local observations exists in the Himalayas<sup>11-13</sup>. Communities whose livelihoods and lives rely on natural resources and ecosystem services are often the first to perceive changes. There has been indigenous knowledge about such changes since many back decades and has been documented in many of the Himalayan studies<sup>12-14</sup> and studies from other similar regions of the world<sup>15,16</sup>.

Several studies evaluating the impact of climate change on forest ecosystems<sup>17,18</sup>, socio-economic conditions and human health<sup>19-22</sup> and land-use pattern<sup>23-25</sup> in India are available. However, the present study deals with climate change-driven livelihood practices from changing land

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**Figure 1.** Study locations in the Indian Himalayan Region.

use and developmental interventions in terms of a comparison between glacier-fed and non-glacier-fed basins in the northwestern to northeastern regions respectively, of the Indian Himalayan Region (IHR). The objectives of the present study were to: identify people's perceptions on climate variability, understand how people's livelihoods and socio-economic conditions are being affected due to climate change, and to assess how vulnerability, and adaptive capacity vary among different communities along with possible adaptive strategies.

### Study area

The present study area includes five different basins across the IHR: (i) Sindh Basin (1683 km<sup>2</sup>), Jammu and Kashmir; (ii) Parbati Basin (1765 km<sup>2</sup>), Himachal Pradesh; (iii) Dhauliganga Basin (1366 km<sup>2</sup>), Uttarakhand; (iv) Ranganadi Basin (2981 km<sup>2</sup>), Arunachal Pradesh, and (v) Imphal Basin (303 km<sup>2</sup>), Manipur (Figure 1).

### Methodology

An in-depth household survey using a common, well-structured questionnaire for all the sites was undertaken in the selected villages of the five basins of the IHR from 2017 to 2018. Exercises such as individual direct interviews and common group discussions were conducted

using a semi-structured questionnaire to obtain people's perceptions regarding impacts of climate change in their areas. The survey was conducted in Hindi and/or local languages for better understanding of the respondents. An overview of the questions framed includes: how changes are taking place in climatic conditions over the years, how climate change is affecting common people's lives, decreasing volume of water bodies and increasing water demand of the people, changing land-use pattern, shift in the vegetation cover and health issues involving increase in flies and mosquitoes, etc.

Overall, 25 villages (five villages per basin) having 994 households were surveyed. The villages from high to low altitude in the Sindh Basin were: Nilgrad (2296 m), Gagangir (2275 m), Drag Tanga (2193), Wail (2188 m), and Preng (1731 m). Villages in the Parbati Basin taken under study were: Nakthan (2672 m), Ucch (2324 m), Tahuk (2287 m) and Shila (2258 m), and Bershaini (2205 m). In the Dhauliganga Basin the villages under survey were: Dar (2175 m), Btan (2145 m), Tejan (1965 m), Gargwa (1714 m) and Sobla (1594 m). The non-glacier-fed villages, Possa (845 m), Peni (631 m), Chulung (648 m), Yazali C-sector (616 m) and Thowu (564 m) were surveyed in the Ranganadi Basin. Five villages, viz. North (1075 m) and South Sapermeina (1049 m), Awang Sekmai (829 m), Motbung (914 m) and Kanglatongbi Mandir (869 m) of the Imphal Basin were surveyed.

Random sampling was adopted covering >30% of the total households in the 25 villages under study. The respondents had spent most of their lifetimes in their respective communities. The age of the interviewees ranged from 25 to 80 years. Special care was taken to select elderly people for the survey, as they are well-experienced. Within each household, mostly the head of the family was interviewed. Along with the family heads, women of the family were also interviewed to represent gender. In view of maintaining gender balance, 50% of those surveyed included women. In addition, youth were also interviewed who had some modern ideas and also could represent new generation.

Daily Climate Forecast System Reanalysis (CFSR) data in terms of different parameters (maximum and minimum temperatures and precipitation) were downloaded and used to study seasonal climatic variations having 38 km horizontal resolution. Climatic data of the past 35 years (1979–2014) for daily maximum and minimum temperatures and precipitation analysis were used. These data were grouped to represent summer (May to September) and winter (November to April) seasons for glacier-fed region. While non-glacier-fed region represented summer from May to October and winter from November to April<sup>26–28</sup>. The rate of increase/decrease of seasonal climatic indices was computed using linear regression slope method. According to this method, the rate of increase/decrease is equal to slope ( $b$ ) of the regression line multiplied by the total number of years of data records. To explain the significance of the observed data, the trends were subjected to one-tailed Student's  $t$ -test at 95% confidence level.

Furthermore, the data collected from questionnaire survey were analysed using chi-square test applied in XLSAT. This was used to test significant differences between responses<sup>29</sup>. The following formula was used

$$\chi^2 = \sum \frac{(O - E)^2}{E},$$

where  $O$  is the observed frequency and  $E$  is the expected frequency in each category.

Regarding adaptive strategies in the wake of climate change threats, a chain of four consultative meetings/capacity-building programmes were conducted in all the five basins under study.

## Results and discussion

### *Climate change and its impacts*

The study explains that most of the respondents (91%) have experienced significant changes ( $P < 0.05$ ) in the glacier-fed basins, particularly in case of Sindh, Parbati

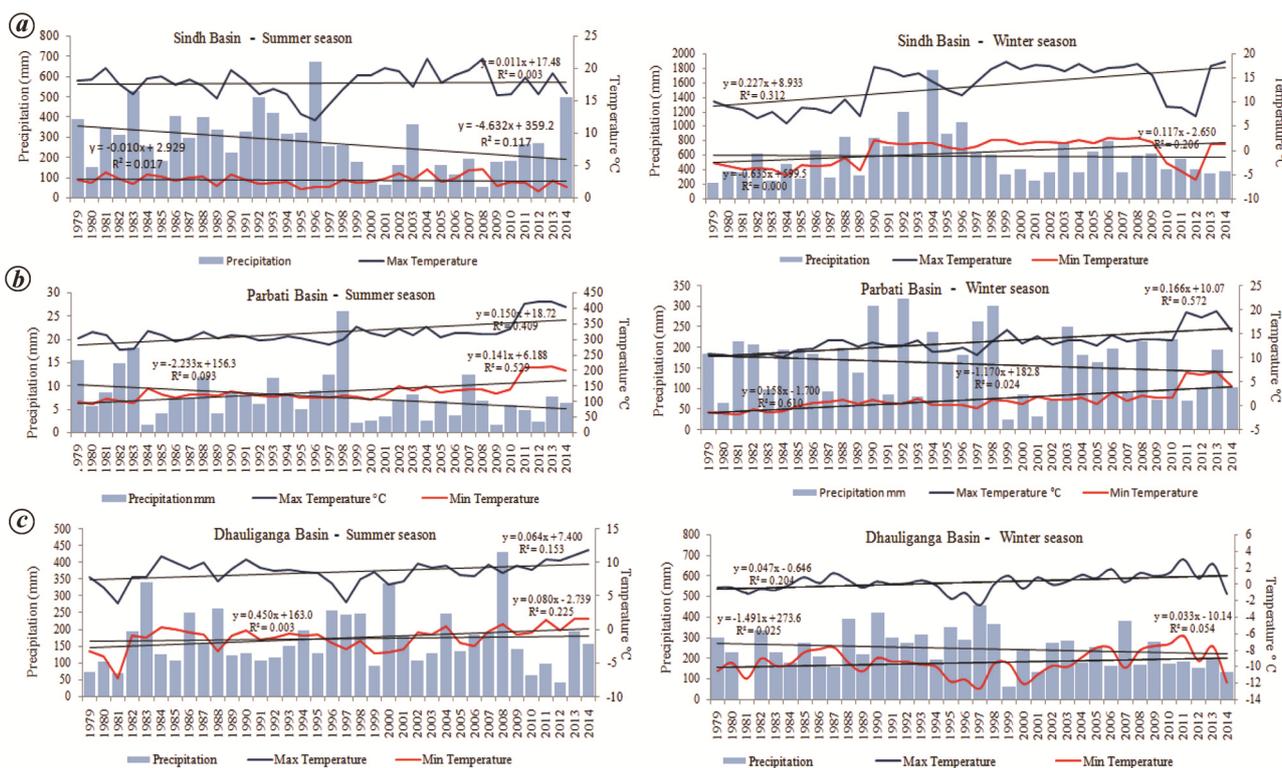
glacier-fed basins and Ranganadi non-glacier-fed basin (Annexure 1). However, in view of changing climate; no such consistency ( $P > 0.05$ ) by 86% respondents was found in other two basins (Dhauliganga glacier-fed and Imphal basin non-glacier-fed). The interviewees were of the view that glaciers in their respective regions are melting fast due to climate change. Similar views were also expressed by other scholars in the recent past. For example, Koul *et al.*<sup>30</sup> studied the Machoi glacier (a source to River Sindh), wherein equilibrium-line altitude (ELA) was shifted from 4540 m amsl in 2011–12 to 4509 m amsl in 2013–14 and the glacier snout advanced 4 m in the central part (3656–3652 m) but either of its side retreated by 0.56 m. Kulkarni *et al.*<sup>31</sup> studied the Parbati glacier which retreated 578 m between 1990 and 2001, indicating almost by 52 m/yr recede. In another recent study of the Parbati glacier, Kuniyal and Samant<sup>32</sup> found that its snout had retreated at an average rate of 0.36 m/yr from 1962 to 2016. The overall recession in snow area of the Parbati glacier from 1962 to 2016 was  $1228 \pm 93.11 \text{ m}^2$ , indicating recession at the rate of  $0.24 \text{ m}^2/\text{yr}$ . Similarly, Singh *et al.*<sup>33</sup> found that nearby glaciers in the Dhauliganga Basin from 1963 to 2016 reduced by approximately  $35 \text{ km}^2$ .

Table 1 provides summary and statistical significance of the rate of increase/decrease of climatic parameters (temperature and precipitation) during winter ( $W_{\text{avg}}$ ) and summer ( $SU_{\text{avg}}$ ) respectively<sup>25</sup>. Figures 2 *a–c* and 3 *a, b* show their graphical representation, while Figure 4 *a–c* shows plots of temporal variation of temperature and precipitation with linear trends. The analysis reveals that the seasonal average temperature shows an increasing trend with different rates in different basins under study, except precipitation trend in winter. In the Sindh Basin, 89% respondents perceived increase in summer temperature, while 79% of the total respondents perceived increase in winter temperature. The results of climatic parameters reveal that in the Sindh Basin, maximum ( $0.011^\circ\text{C}/\text{yr}$  in summer and  $0.227^\circ\text{C}/\text{yr}$  in winter), minimum ( $0.01^\circ\text{C}/\text{yr}$  in summer and  $0.117^\circ\text{C}/\text{yr}$  in winter) average temperatures have shown high rates of increasing trend, which is statistically significant in winter season except a decreasing trend of precipitation ( $-0.635 \text{ mm}$ ) during 1979–2014 (Table 1 and Figures 2 *a* and 4). In the Parbati Basin, 94–97% of the total respondents perceived significant ( $P < 0.05$ ) changes in precipitation (snowfall and rainfall) amount and pattern, whereas 91% and 71% of the total interviewees perceived an increase in summer and winter temperature respectively. The significance test (Student's  $t$ -test at 95% confidence level) in the Parbati Basin shows that the trends of average maximum ( $0.15^\circ\text{C}/\text{yr}$ ) and minimum ( $0.141^\circ\text{C}/\text{yr}$ ) temperatures in summer and average maximum ( $0.166^\circ\text{C}/\text{yr}$ ), and minimum ( $0.158^\circ\text{C}/\text{yr}$ ) temperatures in winter are statistically significant, except precipitation ( $-2.233 \text{ mm}$  in summer and  $-1.17 \text{ mm}$  in winter) indicating a seasonal decreasing trend (Table 1

**Table 1.** Rate of increase/decrease of seasonal average maximum and minimum temperatures (°C) and precipitation (mm) in the Indian Himalayan Region

Basin		Glacier-fed			Non-glacier-fed	
		Sindh	Parbati	Dhauliganga	Ranganadi	Imphal
Summer	Maximum temperature	0.011	0.15	0.064	0.005	0.011
	Minimum temperature	0.01	0.141*	0.08*	0.038*	0.014
	Precipitation	4.632*	-2.233	0.45	7.29	0.789
Winter	Maximum temperature	0.227*	0.166*	0.047*	0.172*	0.065*
	Minimum temperature	0.117*	0.158*	0.033	0.115*	0.017
	Precipitation	-0.635	-1.17	-1.491	-2.775	-0.312

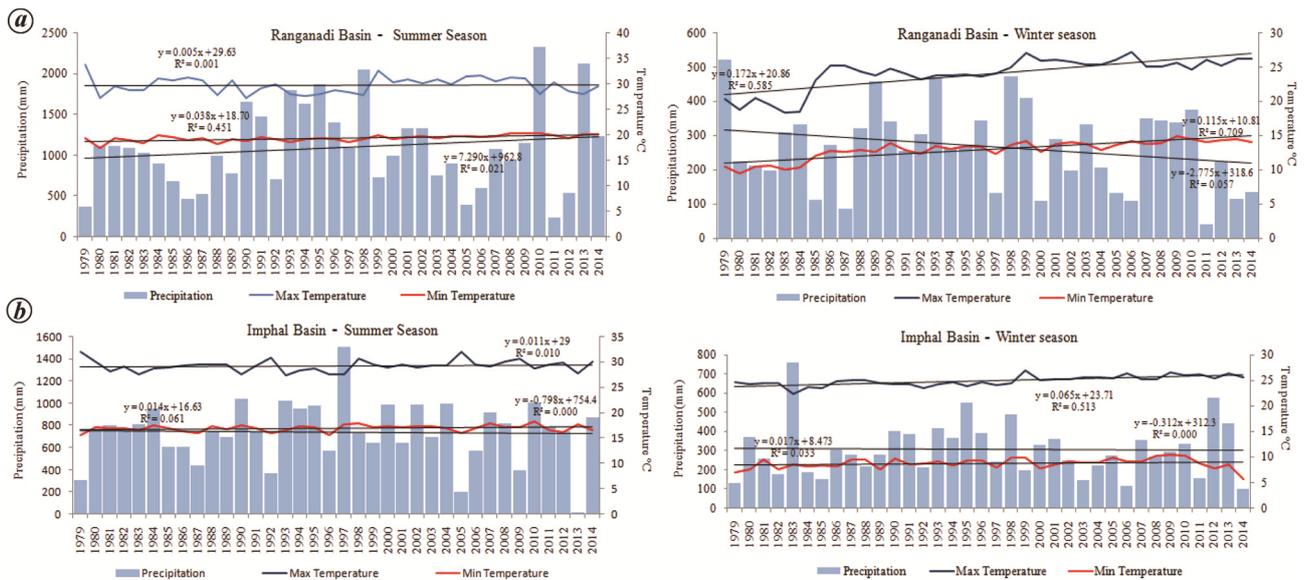
\*Indicates trend statistical significance at 95% confidence level (+ for increasing and – for decreasing).



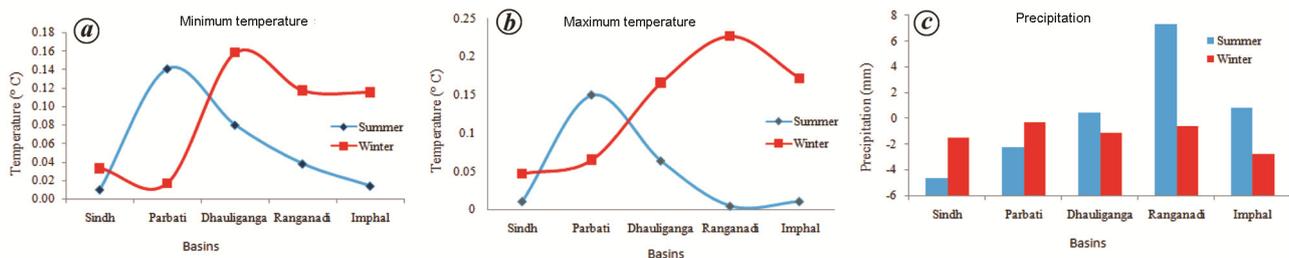
**Figure 2.** Trends in the seasonal average maximum and minimum temperatures (°C) and precipitation (mm) in the glacier-fed regions: *a*, Sindh Basin; *b*, Parbati Basin; *c*, Dhauliganga Basin.

and Figures 2 *b* and 4). About 91% of the total respondents showed significant difference ( $P < 0.05$ ) in the Dhauliganga Basin; they had observed a change in summer temperature along with increasing trend in winter temperature. The significance test shows that the trend of average maximum (0.064°C/yr) and minimum (0.08°C/yr) temperatures in summer and average maximum (0.047°C/yr) temperature in winter is significantly increasing, except precipitation (–1.491 mm in winter) which showed a seasonal decreasing trend from 1979 to 2014. In non-glacier-fed regions, maximum and minimum temperatures in both the seasons showed increasing trend, except precipitation (Table 1 and Figures 3 and 4). Climatic parameters also indicate changing climatic conditions as perceived by people in the IHR. Besides, about

61% of the total respondents showed significant difference ( $P < 0.05$ ) in response to alteration in water bodies and 95% of the total respondents noticed a change in land-use pattern in the Dhauliganga Basin. The present information collected is in line with earlier studies conducted in IHR<sup>34,35</sup>. The chi-square test also showed significant ( $P < 0.05$ ) differences in different responses obtained from the respondents. These are mainly cropping pattern (87%) and land-use pattern (80%). Major drivers of climate change were traced in terms of temperature, rainfall and snowfall, and infestation of pests and diseases (Annexure 1). This finding is consistent with other studies highlighting negative consequences of climate change affecting crop yield and food supply in the region<sup>36</sup>. Besides, climate change has started to affect



**Figure 3.** Trends in the seasonal average maximum and minimum temperatures (°C) and precipitation (mm) in the non-glacier-fed regions: **a**, Ranganadi Basin; **b**, Imphal Basin.



**Figure 4.** Rate of increase/decrease of seasonal average: **a**, **b**, Maximum and minimum temperatures (°C); **c**, precipitation (mm) in the glacier-fed and non-glacier-fed regions.

animal and plant physiology, distribution pattern, phenology and inter-specific interactions<sup>37,38</sup>. Thomas *et al.*<sup>39</sup> predicted extinction of 15–37% of the total species due to anthropogenic activity which account for 20% of the terrestrial surface. With the vulnerability scale being high in the region, a significant change in the climate drivers is marked with magnified consequences in terms of habitat loss, colonization of native habitats by aggressive native colonizers and invasive species. Other than this, changes are reflected as altered phenological events, upward species migration and shifting of tree lines<sup>40,41</sup>.

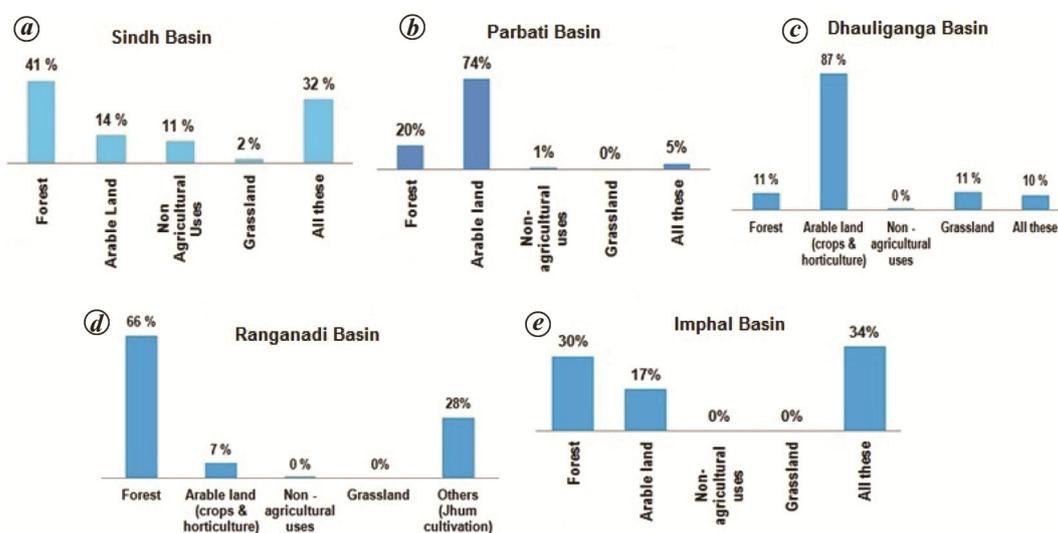
### Impacts on land-use pattern

Change in existing land-use pattern in terms of forest cover was highest in the non-glacier-fed regions, i.e. Ranganadi Basin (66%) followed by glacier-fed regions, i.e. Sindh Basin (41%), although it was least for the Dhauliganga Basin (11%; Figure 5 a–e). In case of per cent change in arable land, its share was highest in Dhauliganga Basin (87%), followed by Parbati Basin (74%)

and was minimum in the Ranganadi Basin (7%). The local people from villages at different altitudes in both the regions mentioned that low rainfall or shift in rainfall pattern had resulted in crop failure, declining yield of food grains and fodder (Table 2), less traditional, horticultural crops cultivation and animal husbandry, but more modern cash crops. The traditional crops will soon be replaced with cash crops like vegetables, peas and potato in higher altitudes (Table 3). It was also reported by the respondents that use of chemicals has resulted in decrease in soil moisture which will be affected by its changing amount, pattern and precipitation cycle. Respondents from Parbati and Dhauliganga glacier-fed basins as well as Ranganadi and Imphal non-glacier-fed basins raised the issue of relatively less scientifically planned road construction in a fragile mountain ecosystem. This makes the region more vulnerable to landslides mainly during monsoon season; and continuously contributes to loss of soil fertility (Table 2). Thus, both anthropogenic and climatic factors appear to be responsible for reducing agricultural productivity. A highly nutritious fodder is gradually disappearing from the forests<sup>42,43</sup>.

**Table 2.** Changes as observed and perceived due to climate change in the IHR

Indicators	Examples
Change in species composition Growth in unpalatable species Decrease in alpine grassland productivity	Transformation in the structure of alpine vegetation, i.e. earlier vegetation of <i>Quercus semecarpifolia</i> and <i>Betula utilis</i> now accompanied by species such as <i>Rhododendron campanulatum</i> , <i>Salix</i> spp., <i>Syringia embodia</i> , etc.
Change in ecotones Loss of habitat Change in land-use practices increases soil erosion/soil fertility and high mortality of species Reduction in agrodiversity and change in crops and cropping patterns	Substantial declining in the population of insectivorous plants, <i>Mantisia</i> spp., <i>Ilex</i> spp., etc. Traditional varieties like paddy, wheat, maize, barley, finger millet, beans, cucurbits and citrus are being replaced by cash crops like potato, pea, etc. Increase in infestation of pests and outburst of new diseases. Expansion of invasive species in croplands like <i>Lantana camara</i> , <i>Parthenium odoratum</i> , <i>Eupatorium hysterophorus</i> , etc. Advancement in flowering cycle of Rhododendron species and members of Rosaceae family (e.g., <i>Pyrus</i> , <i>Prunus</i> spp.).
Increase in temperature Change in vegetation Rapid deforestation Scarcity of drinking water, leading to a great threat to wild flora and fauna Decline in vegetable and fruit crops productivity Reducing chilling hours during winters for fruit yield Degradation of riverine inland ecosystems and associated aquatic biodiversity Increase in invasive insects, pathogens and animals	Cash crops ( <i>Phaseolus vulgaris</i> and <i>Solanum tuberosum</i> ). Yield of apple and citrus fruits. Native fish species like <i>Schizothorax niger</i> , <i>Schizothorax labiatus</i> and <i>Schizothorax plagiostomus</i> have been reduced alarmingly. Species of order Lepidoptera such as <i>Lymantria obfuscata</i> , infest some of the major dominant tree species (i.e. <i>Quercus leucotrichophora</i> , <i>Q. dilatata</i> , <i>Alnus nitida</i> , <i>Salix alba</i> , <i>Falix fragilis</i> and several other popular species), resulting in high mortality rate. Sap sucking insects like aphids such as <i>Tuberolachnus saligus</i> kill its host tree. Croplands are severely damaged due to the menace created by monkeys ( <i>Rhesus macaque</i> ), wild boar ( <i>Sus scrofa</i> ) and other wild animals.



**Figure 5.** Changing land-use pattern in different basins across the IHR.

*Impacts on water resources*

The impact of climate change on the hydrological regime of the Himalayan rivers has been well studied<sup>44</sup>. People’s perception survey on snowmelt contribution, water demand and its sources was conducted in the selected

basins. About 65% of the total respondents were of the view that headwater contribution in the Sindh Basin flow due to snow-/glacier-melt water could be between 75% and 100% (Figure 6 a). Whereas, 33% of the total respondents mentioned that 100% headwater contribution in the Parbati Basin flow is contributed by snow-/glacier-melt

**Table 3.** Changes observed due to climatic variability and their adaptation measures in the IHR

Climatic variability	Changes observed/perceived by stakeholders	Possible adaptation measures	Location
Temperature rise and increased precipitation	Decline in snowfall, unpredictable rainy seasons and their impact on crop sowing time	Cultivation of vegetables like peas and potato at higher altitudes	Glacier-fed regions
Long dry spells	Change in land-use pattern, excessive use of chemical fertilizers to increase soil fertility	Shift in cropping pattern, cultivation practice of cash crops and other varieties relatively with higher yield than age-old traditional varieties with poor yield	Non-glacier-fed regions
		Establishing a balance between traditional staple crops and cash crops	Glacier-fed and non-glacier-fed regions
	Scarcity of water and decline in water quantity in springs and streams, and drying up of natural springs and streams	Focus on rooftop and/or surface run-off rainwater harvesting, rejuvenating and/revival of drying/declining springs, appropriate use of water in the wake of decreasing livestock-rearing in the hills	Glacier-fed and non-glacier-fed regions
		Establishing a balance between pastureland and livestock populations would be within carrying capacity of an ecosystem. Plant species, category of grazing animals, soil characteristics, micro- and regional climate, etc. need to be assessed thoroughly to value and manage ecosystem	Glacier-fed and non-glacier-fed regions
Shift in seasonal cycle of weather; late spell of rainy season (late September) and low winter precipitation (snowfall) in January and February	Decline in forage and fodder produce and livestock population	Planting fodder trees along the edges of terraced fields and rational use of fodder yield through systemic lopping	Glacier-fed and non-glacier-fed regions
	Impacts on limited livelihood options of the local communities	Cultivation of higher fodder-yielding varieties with low grain production	
		Skill development and awareness programmes regarding use of modern tools and techniques in different sectors like beekeeping, poultry farming, fishing, floriculture, handicrafts, carpentry, eco-tourism, medicinal plant cultivation, etc. These alternatives might be potential to sustain local livelihood options	Glacier-fed and non-glacier-fed regions
Change in forest area	Forest clearance for agriculture, tea cultivation, slash and burn mode of cultivation with ever-reducing 'jhum' cycle, and alteration of prime natural habitat for developmental and industrial activities	Rejuvenation of the culturable waste, degrading and barren lands through afforestation and reforestation programmes	Non-glacier-fed regions
Impact on agriculture	Decrease in crop production; crop failure due to unpredictable rainfall, hailstorms, flash flood and infestation of pest and diseases	Strengthening irrigation practices, rationale use of high yielding/drought and disease resistant varieties of crops	Non-glacier-fed regions

water (Figure 6 *b*). About 1% of the total headwater contribution in the River Dhauliganga comes from snow/glacier melt, while maximum respondents (93%) did not reply to this question (Figure 6 *c*). The Ranganadi and Imphal basins are non-glacier-fed and here respondents were of the view that snow/glacier had no role in the river flow and rainwater was the only contributor to the same.

In the wake of climate change, rapid snow/glacier-melt accelerates river run-off, which is reported to reduce the ice reserve below a critical threshold. For instance, it re-

sults in catastrophic floods that sometimes are referred to as the 'mountain tsunamis', which can deprive people of all means of livelihood in a single stroke<sup>45</sup>. In the glacier-fed region in the Sindh Basin, 91% respondents witnessed alteration in water bodies. Similar results were obtained from non-glacier-fed region in the Imphal Basin, where about 86% of the total respondents perceived change in volume and drying up of the water bodies. In the Imphal Basin respondents perceived that warmer climate has led to uncontrolled growth of weeds in the lakes that pollute the water. Increasing floating biomass (phumdi) in

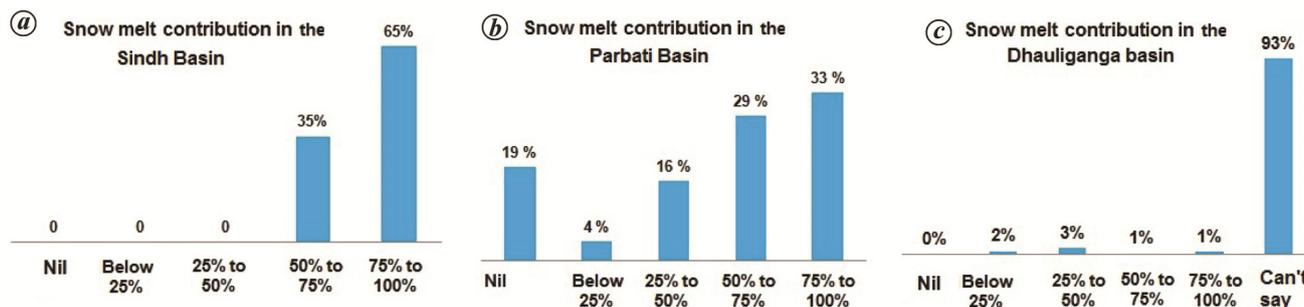


Figure 6. Snowmelt contribution in different river basins.

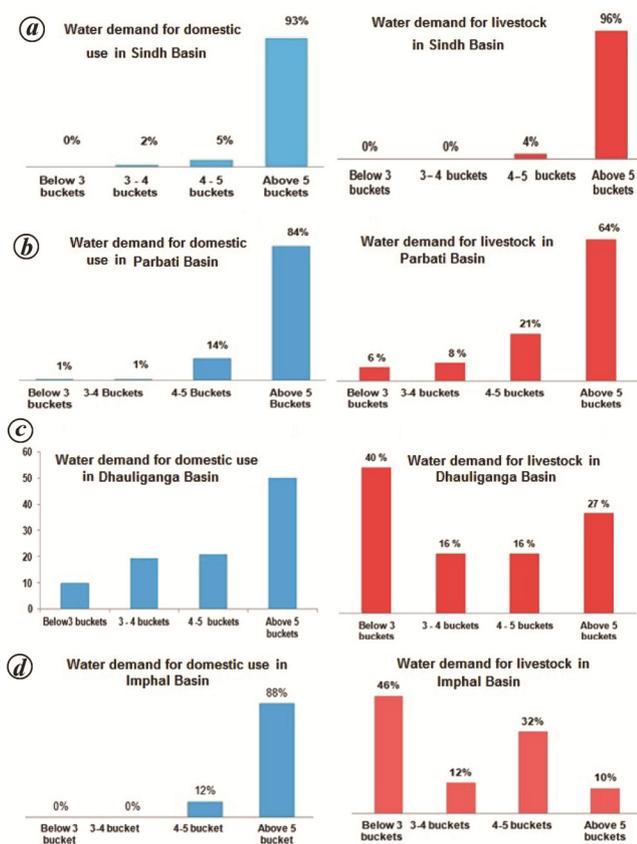


Figure 7. People’s perception on water demand for domestic and livestock purposes in the glacier-fed and non-glacier-fed regions.

Loktak Lake may be one of the examples of climate change.

The other responses were on water demand and its usage. On an average, about five buckets of water per day (1 bucket = 15 l), accounting for about 75 l/day for both domestic as well as livestock population was needed (Figure 7 a–d). The major sources of water are small streams, springs, hand pumps and perennial rivers. The rising temperature will have its impact on the hydrological cycle, as it will cause snowline shift upwards and reduce snow storage capacity of the basin. In the monsoon season, more rainfall contributes to more surface run-off

further creating flood conditions, while less run-off in summer season will have an impact on irrigation and hydropower sectors. Some studies have been conducted on global warming and its impact on melting of glaciers in the Himalaya<sup>32,46,47</sup>. In the long-run, this can adversely affect the hydropower projects causing deficit in water supply as raw material and also high debris flow from the moraines and ultimately its deposition in the dams<sup>48,49</sup>. Water quality is important for good health in these high-altitude regions, so there is a need to develop water purification systems in view of maintaining its quality at both individual and community levels.

### Impact on forests

Change in forest ecosystem and its composition is vividly reported by the respondents in glacier-fed regions like the Sindh Basin, wherein about 85% of the respondents reported a shift in vegetation species to higher altitudes. The notable tree species among these include: *Betula utilis* and *Pinus wallichiana*. Also, 67% of the total respondents reported a change in this basin in terms of plant species composition in genus *Pinus* and *Betula*, which were rarely seen at higher altitude (Table 2). A similar change was reported in the Parbati Basin, where 60% of the respondents attributed this to: (i) road construction activities, (ii) increased fuelwood consumption with ever-increasing human population, (iii) vegetation loss due to natural disasters – cloud bursts, flash floods, forest fires, etc., (iv) over-grazing and (v) decreased regeneration rate of trees in the forest area. Likewise, the non-glacier-fed regions like Imphal Basin showed shifting of plant species to higher altitudes and over the years this has been supported by about 12% of the total respondents (Annexure 1 and Table 2). A low diversity in the Changoubung forest due to repeated felling, and slash and burn (jhum) cultivation by the natives, and spreading of *Tithonia diversifolia*, *Lantana camara* and *Mikania*, etc. together have resulted in forest loss. The structure of the forest is further going to change when dependency on the forest resources increases as a result of low agricultural produce and extreme climatic events like cloud bursts and flash floods.

### *Impact on human beings*

The change in weather pattern also influenced human health, and altered range and seasonality of outbreak of vector-borne infections, e.g. malaria, dengue fever, etc. in all the study basins (Annexure 1). A study conducted on climate drivers on malaria transmission in Arunachal Pradesh<sup>50</sup>, had revealed that climatic variables such as temperature and rainfall are the major influencing factors for the high rate of malaria transmission in East Siang district of the state.

### *Capacity-building programme and social awareness*

Taking into consideration the complexities and adversaries within the forest ecosystem, adaptation as a result of climate change in recent years has become the key focus of scientific studies and policy guidelines. These aspects have now become important topics of discussion in the multi-lateral process<sup>51</sup>. Formulating adaptation strategies is a key factor that will not only make us conscious about the happenings in the real world, but also indicate future severity of climate change on different environmental sectors. These adaptations will require substantial involvement by farmers, governments, scientists and developmental organizations.

In view of knowing the views of the local communities for adaptation and resilience-building due to climate change, a series of four consultation meetings/capacity-building programmes of the local stakeholders in the IHR were organized. Some of the opinions were considered for formulating mitigation measures and adaptive strategies. The first consultative meeting was conducted on 22 and 23 November 2017 at Gagangir village in the Sindh Basin (Jammu & Kashmir) wherein 74 participants took part. During the interactive session, the villagers raised issues like scarcity of drinking water supply, lack of tourism development, lack of road connectivity, upgradation of health and educational facilities, etc. They emphasized on deteriorating quality of drinking water which in a polluted form has been causing water-borne diseases because of an ongoing tunnel construction work. This tunnel would ensure all-weather connectivity between Srinagar and Kargil in the Ladakh region. The local people were of the view that the construction activity has deteriorated the surrounding fragile environment along with the headwater regions of the River Sindh<sup>52</sup>. Besides, people also mentioned that the valley has been witnessing extreme weather conditions such as torrential rainfall, cool summers, increasing hailstorms and cloudbursts. The disastrous effects of changing climate in the form of heavy rainfall was witnessed in Kashmir valley during 2014, causing damage to lives and property<sup>53,54</sup>.

The second workshop was organized from 1 to 3 December 2017 with 25 participants at CSIR-North-East

Institute of Science and Technology, Lamphelpat-Imphal in the Imphal Basin in Manipur. Representatives from the Loktak Development Authority in Manipur raised issues related to the presence of phumdi (floating biomass) in the Loktak Lake causing excessive proliferation, thus deteriorating water quality, dwindling fishery resources and degradation of catchment due to siltation<sup>52</sup>. They also mentioned the problem of low diversity in the Changou-bung forest due to repeated felling and burning for jhum cultivation by the local communities, heavy invasion by *T. diversifolia*, *L. camara* and *Mikania*, etc. Unpredictably, change in monsoon in terms of irregular distribution of rainfall has affected many livelihood sectors as well as vegetation in the region. The people mainly depend on local forest products and rainfed agricultural practices for their livelihood.

The third consultative meeting convened on 7 December 2017 at Old Ziro in the Ranganadi Basin with 28 participants and discussed the issues like scarcity of water for drinking and irrigation practices. Representatives were also of the view that water in their region is getting polluted day-by-day, and the main causes were attributed to deforestation, waterlogging, mining and non-plantation of native species. In addition, issues like shrinking agricultural land and landscape degradation were raised by the Ziro Biodiversity Management Committee (ZBMC), especially due to unchecked construction activities which have severely hampered tourist inflow in the valley<sup>52</sup>. The feedback received from the stakeholders was proper planning and management of newly constructed houses on a priority basis. At the same time, ritualistic activities need to be revived to maintain traditions.

The fourth but important consultative workshop was conducted on 27 December 2018 at Gram Panchayat Bershaini in the Parbati Basin with 45 participants. The president of the Panchayat (Pradhan) spoke in detail about the problem of solid waste management and its reuse options. Lack of awareness about solid waste management in the region was attributed as the biggest hindrance to the Swachh Bharat Mission. The head of the women's group (Mahila Mandal) raised issues related to scarcity of water for drinking and irrigation in the valley. The other issues mentioned were decrease in snowfall amount over the years. The changes in snowfall pattern in the region were linked with developmental activities like hydropower projects, constructions, etc. Skill development programmes especially for women were suggested such as bee-keeping, knitting and embroidery to enhance their livelihood options. In addition, microbial bio-composting from biodegradable solid waste was another probable livelihood option. The overuse of pesticides and loss in soil fertility were also raised from the angle of the farming community. Representatives from the hoteliers' association raised the problem of waste management and lack of infrastructural facilities with respect to tourism activities<sup>52</sup>.

**Annexure 1.** Climate change, its impact and changing land-use pattern in different basins of the IHR

Question	Glacier-fed basins						Non-glacier-fed basins													
	Sindh n = 347		Parbati n = 148		Dhauliganaga n = 144		Ranganadi n = 110		Imphal n = 245		χ <sup>2</sup> test	χ <sup>2</sup> test								
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No										
Is climate change taking place?	91	3	6	0.01792**	95	2	3	0.001**	99	1	1	0.3940	86	7	7	0.0176**	90	10	0.38516	
Is there a change in rainfall pattern?	93	3	4	0.165	94	3	4	0.16	99	1	1	0.05856**	100				84	14	2	0.008817*
Is there a change in snowfall pattern?	81	15	4	0.05039**	97	3	3	0.07	99	1	1	0.011889**	NA	NA	NA					100
Is there an increase in summer temperature?	89	5	6	0.9999	91	8	1	0.367	91	7	2	0.000158**	34	55	10	0.0506**	100			
Is there an increase in winter temperature?	79	16	5	0.97677	71	28	1	<0.0001**	91	7	2	0.00254**	83	17	17	0.4596	100			
Is there a change in land-use pattern?	87	7	6	0.957198	80	14	6	0.001**	95	5	5	0.0002283*	NA	NA	NA		36	44	20	0.534445
Is there a change in cropping pattern?	68	17	15	0.99075	87	8	5	0.002**	95	5	5	0.181376	NA	97	3	0.4285	16	38	46	0.310513
Is there an upward shift in vegetation species?	85	9	6	0.03503**	60	14	26	0.0051**	28	37	35	<0.0001**	NA	NA	NA		12	32	56	<0.0001*
Is there a change in composition of plant species?	67	23	10	0.00069**	59	31	10	0.1570	5	63	32	<0.0001**	97	NA	3	0.4756	2	36	62	0.8885
Is there a change in volume or decrease in water availability?	91	6	3	0.8664	83	11	6	0.07	61	28	10	<0.0001**	NA	NA	NA		86	-	14	<0.0001**
Is there an increase in new pests/weeds in crops?	63	19	18	0.533239	37	52	11	<0.0001**	16	34	50	<0.0001**	NA	NA	NA		4	20	76	0.00017*
Is there an increase in flies, mosquitoes and new diseases?	78	12	10	0.872622	88	8	4	<0.0001**	98	2	2	0.07691	100				94	6		<0.0001**

Note: NA, Not available; \*Significant at P < 0.05, \*\*Significant at P < 0.01, not significant if P > 0.05.

### *Response and adaptation measures to climate change by the community*

The mountain ecosystem relies on seasonal rainfall and weather conditions which in the global context have been continuously changing. The impacts have been experienced over the last decades in the form of irregular rainfall, changes in its frequencies and volume, and rising temperatures leading to low agricultural crop production. Climate change has resulted in an increase in pests, diseases and invasive species (e.g. *Eupatorium*, *Lantana*, *Parthenium*), which directly affect crop productivity and food safety. During pandemic situations like COVID-19, self-reliant system with conservation and management practices of locally available resources or income sources may prove to be vital and sustainable. Further, rational use of locally available resources and confining diseases like COVID-19 at a place only would promote 'vocal for local' in the marginal areas and concerned communities in the Indian Himalayan Region. Table 2 describes the significant changes caused by climate change as experienced by the conventional societies in rural India. In order to cope with these changes, some of the communities have adapted measures based on their past knowledge and rich experience in glacier-fed and non-glacier-fed mountain regions (Table 3).

### **Conclusion**

Synthesis from a perception based study highlights snowmelt contribution impacting river run-off. In addition, respondents were well aware of the ongoing phenomenon of climate change along with its future implications in their immediate region, as supported by analysis of seasonal climatic parameters (temperature and precipitation) for 35 years (1979–2014). The other natural resources likely to be impacted adversely were forests and change in land-use pattern. This is evident from a majority of the respondents who had supported the view that road construction, forest fires and over-grazing have multiplier negative impacts on the forest ecosystem and land-use pattern over the years. The implementation of mitigating measures and adaptation strategies is rarely taken into account at local, regional and national levels. In a nutshell, a number of consultation meetings/capacity-building workshops were conducted throughout the IHR. The problems raised by the villagers were more concerned with climate change and associated livelihood options. These communities are reacting to the changing scenario in a positive manner. They have begun some practices with reasonable adaptive measures. However, these are very few at the local level and need further expansion in states of the IHR. Therefore, a detailed study is required to plan future adaptation strategies that will improvise traditional practices with modern science and technology.

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ACKNOWLEDGEMENTS. We thank the Director, Govind Ballabh Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora for providing the necessary facilities, and the Ministry of Environment, Forest and Climate Change, Government of India for financial support under the National Mission on Himalayan Studies to conduct this work.

doi: 10.18520/cs/v120/i5/888-899