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Climatic variations and livelihood adaptations in cryosphere district of Uttarkashi, Uttarakhand: A local public perception approach

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Abstract

This paper is a perception-based study that aims at understanding the impact of climatic variability on livelihood opportunities in the Cryosphere highland of mid-Himalayan region. The region faces environmental challenges affecting livelihood linkages linked to agriculture. Data analysis involves descriptive statistics, bi-variate analysis (chi square and likelihood ratio) and logistic regression to understand issues and association. There is significant association between climatic variables and livelihood options. Logistic regression model shows that there is an integrated impact of climatic factors such as precipitation and temperature etc. on snowline change. A similar integration was also found on altitudinal change in vegetation. Local people's perception reflects changing livelihood options with the changes in climate.

Keywords: *Cryosphere, livelihood adaptation, indigenous practices, local public perception approach.*

Introduction

Livelihood concerns due to climate variability and climate change is a major concern in the high-altitude regions. High altitude regions are abode of many glaciers that is a frozen mass of ice and other earthen materials, known as cryosphere (Mukherji et al., 2019; Bajracharya et al., 2015). Globally, mountains are the source of multiple ecosystem services, with a vast area covered by Cryosphere (Jodha, 1992; Dyurgerov and Meier, 2005; Mukherji et al., 2015). The livelihood of people in mountainous area is vulnerable to cryosphere change as they have to depend on the available natural resource for their survival (Messerli & Ives, 1997; Ranjan et al. 2016; Ranjan et al. 2020). The Cryosphere changes are first experienced at the local level where the indigenous communities are closely interwoven with the natural resources, climatic variations and local cultural belief (Beniston, 2003; Joshi et al., 2015). Cryosphere changes and its consequences, as reported by the people living in this fragile ecosystem, include irregularities in rainfall, shortening of the winter season, increase in temperature, reduction in snow-cover and snowfall, and changes in the distribution of the indigenous species of flora and fauna in the region (Negi, 2012; Paudel & Andersen 2013; Ranjan et al. 2020). Drastic anomaly

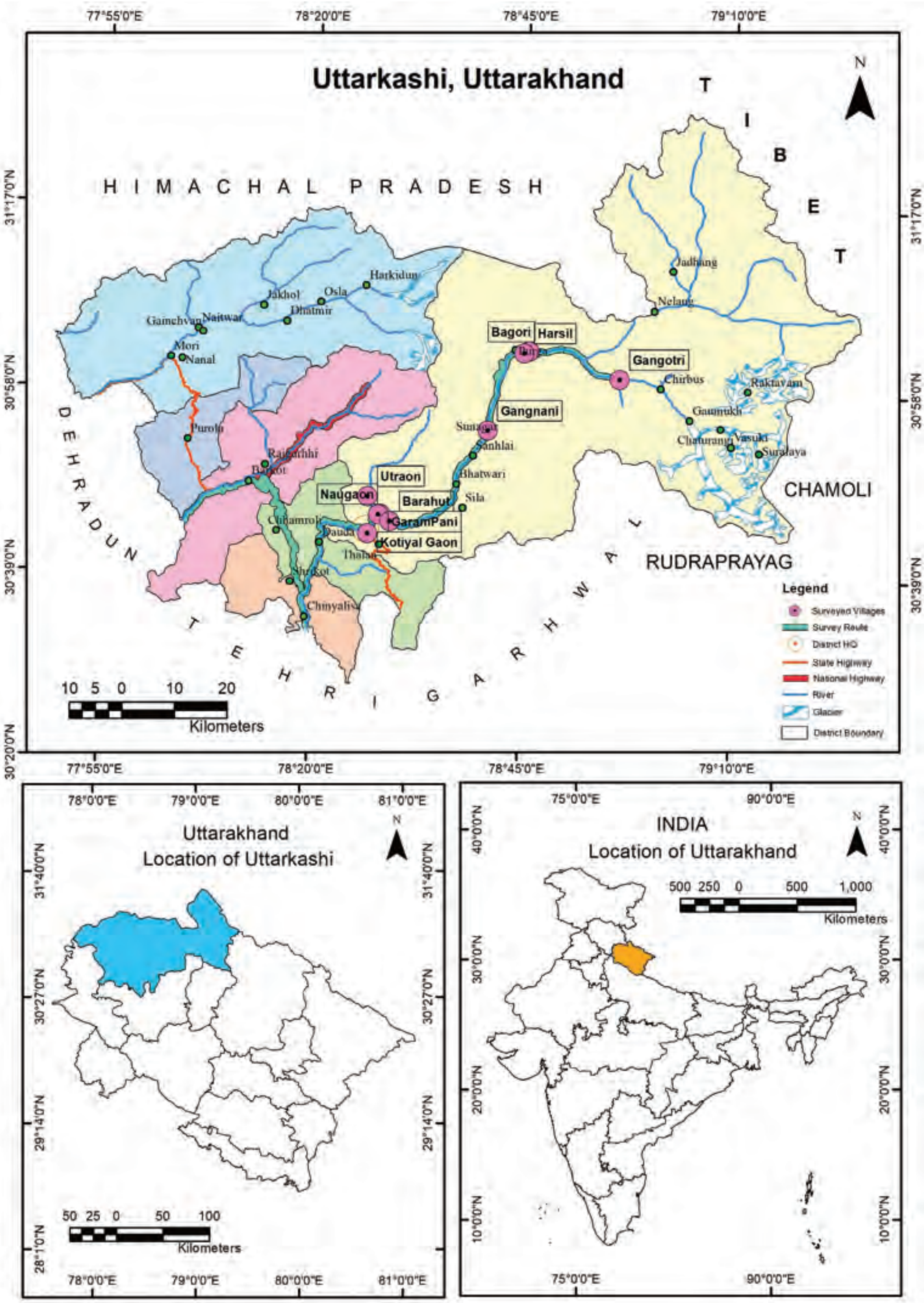

Fig. 1: Location of surveyed villages

Source: Prepared by the authors, 2021

in climatic parameters like temperature, snowfall, rainfall and surface runoff in more recent times however are felt by the inhabitant which has a direct and immediate effects on their livelihoods (Mc Dowell et al., 2019; Dimri et al., 2021).

Studies have revealed subtle but significant change in the climatic system and growing incidents of natural hazards such as Glacial Lake Outburst Floods (GLOF), flash floods, avalanches and landslides etc. (Negi, 2012; Mukherjee et al., 2019). Needless to say, the local community historically has adapted to the variable climatic conditions, but the complex inter-linkages between the society, economy, cryosphere change and environment poses a serious challenge to the community (Mukherjee et al., 2019; Mamgain & Reddy, 2017; Mishra and Pandey, 2019). The Cryosphere is a great source of melt-water that feeds more than half of the global population through highland and lowland interaction (Messerli & Ives, 1997; Pandey, 2000; Mc Dowell et al., 2019; Rasul et al., 2020). It supports agriculture, horticulture, livestock, small hydropower projects, tourism and is a great source of livelihood options (Nusser et al., 2017). The rate and magnitude of recent changes however is a threat to the current adaptive capacity and resilience of the environment (Mukherjee et al., 2019). The inhabitants in these highlands, based on indigenously acquired knowledge have developed unique coping strategies to deal with the changing weather phenomena (Semwal et al., 2004; Ranjan and Anand, 2017), so essential to tackle the unavoidable irreversible change for maintaining and managing issues of food security and livelihood options (IPCC, 2014; McDowell et al. 2019). Livelihood and cryosphere dynamics are closely interlinked and any change in it has significant adverse effects on the local inhabitants (Mittal, et al. 2008; Talukdar et al., 2021).

Study area

Uttarkashi district, the area for the present study is situated on the banks of river Bhagirathi located in the state of Uttarakhand in India. The district lies between latitude 30º28’ N and 31º28’ N and longitude 77º49’ N and 79º25’ N covering an area of about 8016 km^2 with an altitude ranging between 1200 and 7000m (Census of India, 2011; GOI, 2019) experiencing great temperature range from minimum 1.6ºC to maximum 34.4ºC. The district had a population of 330,000 in 2011 with a decadal growth rate of 11.89 percent (Census of India, 2011). A district vastly rural in its population composition had only 7.36 percent of its total population living in urban areas (Census of India, 2011). Six villages of the district, namely, *Harshil, Ganeshpur, Garampani, Bagori, Kot Mangla* and *Mukhwa* have been surveyed for the study. The surveyed villages were selected on the basis of their close proximity and dependence on the water resources (Fig. 1).

Data and methodology

The paper is concerned about the dynamics of livelihood under the impact of climate change in the cryosphere region of Uttarakashi based on both primary and secondary sources of data. The major source of the data is collected from selected villages where the perception of the inhabitants was collected with the help of a structured schedule to obtain information on climate change induced livelihood concerns. Techniques such as Participatory Rural Appraisal (PRA), field survey, interview and focused group discussions were conducted for preparing the questions and dimensions that are manifest in the area of the study. A total of 100 households have been selected in the study as per probability proportional to size of the population of the selected villages. Stratified Random Sampling (SRS) technique has been used for the selection of the households. The sample villages were selected on the basis of relief i.e. 3000 metres and above, 3000 metres to 2500 metres and below 2500 metres elevation from the mean sea level. The secondary data were collected from several published literatures to corroborate the findings and to validate them from primary data for reliable outcomes. Bivariate analysis (Chi square and likelihood ratio) has been used to measure the two-way relationship with the number of variables undertaken for the study. *Logistic regression* (classification algorithm) has been used to predict a binary outcome based on a set of independent variables. Similarly, the direction of the relationship has also been measured. Logistic regression is best suited to see the relationship of independent variables to dependent variables that are categorical in nature.

Results and discussion

Estimation of Agricultural Component

The primary data has been collected to identify the various aspects and impact of climate variability on the local livelihood.

Equations

(I) Chi square test- $x^2 = \sum(o - e^2/e$ … … … …Eq. (i)

Where, o = observed frequency; e = expected frequency; $\sum$ = summation; x^2 = chi-square value

(II) Likelihood ratio of chi square-

If X_i is discrete data, the function can be expressed as

(III) $L(m_1, m_2 , \ldots . . m_n ; \theta) = P_{M_1.M_2 \ldots\ldots M_n}(m_1, m_2, \ldots m_n; \theta)$ … Eq. (ii)

If X_i is jointly continuous data, the function can be expressed as

$$L(m_1, m_2 , \ldots . m_n ; \theta) = f_{M_1.M_2 \ldots \ldots M_n}(m_1, m_2, \ldots \ldots m_n; \theta) \quad . \ldots \text{Eq. (iii)}$$

(IV) Logistic Regression model

$$\text{logit } (\mathcal{E}[Yi|Xi]) = \text{logit}(\mathcal{P}i) = \text{In} \frac{\mathcal{P}i}{1-\mathcal{P}i} = \beta . Xi \quad \ldots \text{Eq. (iv)}$$

where, β is the parameters of the logistic regression coefficients; $Xi \text{ and } Pi$ and one binary variable; $\mathcal{P}$ is the probability

Table 1: Proportion estimation for agricultural component

	Proportion	St. Err.	95 % Confidence Interval	
Marginal land holdings	0.58	0.050	0.480	0.674
Small land holdings	0.41	0.049	0.317	0.510
Semi-medium landholdings	0.01	0.01	0.001	0.070
Rice				
Cultivated	0.18	0.039	0.116	0.269
Wheat				
Cultivated	0.25	0.044	0.174	0.346
Apple				
Cultivated	0.5	0.050	0.402	0.598
Potato				
Cultivated	0.77	0.042	0.676	0.843
Others				
Cultivated	0.81	0.039	0.719	0.876
Crops growing cycle				
One season	0.25	0.044	0.174	0.346
Two seasons	0.57	0.050	0.470	0.665
Three seasons	0.18	0.039	0.116	0.269
Mixed cropping Followed	0.67	0.047	0.571	0.756
Insecticide and pesticides use for weed management	0.34	0.048	0.253	0.440
Use of traditional method of weed management				
Yes	0.76	0.043	0.665	0.835
On farm fertilizer				
Yes	0.74	0.044	0.644	0.818
Government Fertilizers				
Yes	0.57	0.050	0.470	0.665
Private fertilizer resource				
Yes	0.17	0.038	0.108	0.258
Organic method				
Yes	0.85	0.036	0.764	0.908
Inorganic method				
Yes	0.37	0.049	0.280	0.470
Commercial crops				
Yes	0.59	0.049	0.490	0.683
Crop selling				
Direct selling	0.68	0.047	0.581	0.765
Through middlemen	0.27	0.045	0.191	0.367
Through agencies	0.05	0.022	0.021	0.116

Source: Computed by the authors on STATA 13.0, based on field survey, 2021

The primary economic activity of Uttarkashi district is agriculture. As per district census handbook (Census of India, 2011), more than 21.4 percent farmers have landholding below 1 hectares (marginal), while 26.3 percent farmers have 1-2 hectares land (small). Wheat and rice are the dominant crops cultivated. About 23 per cent of farmers cultivate wheat and 18 percent of them grow rice. Potatoes are the only dominant commercial crops cultivated by 77 percent of the farmers. The agro-ecological conditions favour cultivation of apples which is grown by half of the farmers. These crops are grown seasonally depending upon varied climatic conditions and topography. Agriculture is practiced in one, two or three seasonal cycles whose contribution is 57 percent, 25 percent and 18 percent respectively. Weed management is essential for the healthy growth of crops. Around 76 percent of the farmers practice traditional method of weed management. Majority of the farmers (74%) uses farm resources as manure. A great majority of the farmers (85%) practice organic farming whereas many of them (37%) still practice inorganic farming. More than 59 percent farmers grow commercial crops that suit the local climate. 67 percent farmers follow the mixed cropping pattern. Table 1 provides the details.

Factors affecting agricultural output

Production and productivity of crops depend on soil fertility, slope, micro-climatic conditions, capital investment and use of farm implements. The past few decades have witnessed small but significant changes in climatic parameters like irregular rainfall, decrease in snowfall, and rise in temperature etc. which has consequences for local environment and livelihoods in the districts. Frequency of hazards like cloud bursts, flash floods in lower valleys, landslides and avalanches etc have increased adversely affecting crop production. The farmers view natural calamity, apart from disease and pest attacks, as the most important factor (57%) threatening crop production followed by attacks from wild animal (51%), lack

Table 2: Factors affecting agricultural output

	Proportion	St. Err.	[95 per cent confidence Interval]	
Natural calamity				
Yes	0.57	0.050	0.470	0.665
Wild animal				
Yes	0.51	0.050	0.411	0.608
Lack of finance				
Yes	0.52	0.050	0.421	0.618
Unavailability of resources				
Yes	0.57	0.050	0.470	0.665
Pest and diseases				
Yes	0.60	0.049	0.500	0.693
Others				
Yes	0.47	0.050	0.373	0.569

Source: Computed by the authors on STATA 13.0, based on field survey, 2021

of finance (52%), unavailability of seeds, irrigation, pesticides, etc. (52%), and other factors that affect the agriculture (47%) (Table 2). Disease and pests are however common threats to crops all over the world.

Bivariate analysis: Chi-square

The Chi-square test is a non-parametric test that measures the difference between the observed and the expected variable depending on the assumed hypothesis. The chi-square test has been conducted on various aspects of climatic parameters. In table-3 the first row shows the frequency of data while the second shows the row percentage and the third row shows column percentage of total specific responses i.e. yes, or no. For example, 15, 6 and 21 in the natural change section are just number of respondents but 71.43 percent 28.57 percent are row percentage of no-change in climate in relation to naturally occurring changes, calculated from 15 out of 21 and 6 out of 21 respectively. The values of 30.61 percent and 11.76 percent are column percentage values for climate change attributed to natural changes, calculated on 15 out of 49 and 6 out of 51. The relationship between climate change perception and natural change in the parameters of climate without any anthropogenic intervention shows a strong relation between them based on the p-value of Pearson chi-square and the likelihood ratio. There are 79 percent respondents who believe that climate change is happening, and a majority of them (56.96%) believe it to be naturally induced. Overall a little over half of the respondents attributed climate change to natural causes while the rest attributed it to reasons other than natural causes. An overwhelming 88.26 percent of those who believe that natural changes responsible for climate change also believe the latter to be real. The p value of Pearson chi-square is 0.021 which is less than the observed p-value of 0.05 (Table 3) and hence statistically significant. The likelihood

Table 3: Association between climate change perception and climate change attributed to natural change.

Climate change perception	Climate change attributed to natural change		
	No	Yes	Total
No change	15	6	21
	71.43	28.57	100.00
	30.61	11.76	21.00
Change	34	45	79
	43.04	56.96	100.00
	69.39	88.24	79.00
Total	49	51	100
	49.00	51.00	100.00
	100.00	100.00	100.00

First row has *frequencies*; second row has *row percentages* and third row has *column percentages*
Pearson chi^2 (1) = 5.3509 pr = 0.021 p = <0.05
Likelihood-ratio chi^2 (1) = 5.4815 pr = 0.019
Source: Computed by the authors on STATA 13.0, based on field survey, 2021

Table 4: Association between anthropogenic change in climate and increase in temperature

Anthropogenic induced change to climate	Temperature		
	No change (Stable Temperature)	Increased Temperature	Total
	16	18	34
No	47.06	52.94	100
	51.61	26.09	34.00
	15	51	66
Yes	22.73	77.27	100
	48.39	73.91	66.00
	31	69	100
Total	31	69	100
	100.00	100.00	100.00

First row has *frequencies*; second row has *row percentages* and third row has *column percentages*
Pearson chi^2 (1) = 6.2109 pr = 0.013
Likelihood-ratio chi^2 (1) = 6.0571 pr = 0.014
Source: Computed by the authors on STATA 13.0, based on field survey, 2021

ratio p-value is only 0.019 showing stronger relationship between climate change and natural change in the climatic parameters without any anthropogenic intervention.

It is evident from table 4 that a great majority of 77 per cent who believed that anthropogenic factors to be largely responsible for climate change felt the habitat is experiencing significant increase in temperature while the remaining did not feel any significant change to temperature. A little over one third of the respondents found anthropogenic impact on increased temperature to be of little consequence. The Pearson chi-square p-value and likelihood ratio p-value are 0.013 and 0.014 respectively signifying a strong relationship between anthropogenic change and increase in temperature.

Table 5 shows that a majority (58%) of the respondents believed the region to have experienced altitudinal shift in vegetation. The p-value for both Pearson chi-square and likelihood is 0.000 i.e. less than 0.05 which is highly statistically significant indicating a strong relationship between the increase in temperature and the altitudinal change in vegetation. The change in the vegetation cover implies shift in the tree line from the lower altitudinal position to higher altitudinal position. There is a change in the nature of trees grown in an area over the years as tree species grow at a certain altitude, with the change in temperature regime. About 75.36 percent respondents of those who perceived significant increase in temperature also believed that there was an altitudinal change in vegetation cover. About 80.65 percent respondents of those who experienced no change in temperature over the years however felt that there was no altitudinal change of vegetation cover.

Table-6 reveals that the people (70%) are aware of melting of glaciers in the region. A significant proportion (81.16%) who felt

Table 5: Association between altitudinal change of vegetation cover and temperature

Increase in temperature	Altitudinal change of vegetation cover		
	No change	Changed	Total
No change	25	6	31
	80.65	19.35	100.00
	59.52	10.34	31.00
Increased	17	52	69
	24.64	75.36	100.00
	40.48	89.66	69.00
Total	42	58	100
	42.00	58.00	100.00
	100.00	100.00	100.00

First row has *frequencies*; second row has *row percentages* and third row has *column percentages*
Pearson chi^2 (1) = 27.5439 pr = 0.000
Likelihood-ratio chi^2 (1) = 28.5480 pr = 0.000
Source: Computed by the authors on STATA 13.0, based on field survey, 2021

Table 6: Relationship between temperature and melting of glaciers in the region

Increase in temperature	Glacier melting		
	No change	Melting	Total
No change	17	14	31
	54.84	45.16	100.00
	56.67	20.00	31.00
Increased	13	56	69
	18.84	81.16	100.00
	43.33	80.00	69.00
Total	30	70	100
	30.00	70.00	100.00
	100.00	100.00	100.00

First row has *frequencies*; second row has *row percentages* and third row has *column percentages*
Pearson chi^2 (1) = 13.1993 pr = 0.000
Likelihood-ratio chi^2 (1) = 12.7099 pr = 0.000
Source: Computed by the authors on STATA 13.0, based on field survey, 2021

increase in temperature in the recent years also noticed melting of glaciers in the region. A relatively high proportion of the respondents (45%) who felt that there was no change in temperature also believed in accelerated melting of glaciers. This is significant in a sense that rise in temperature is not the only factor behind melting of glaciers but there are other factors as well. Both the Pearson chi-square p-value and likelihood value are 0.000 which is less than 0.05. It shows a very strong relationship between the increase in temperature and the melting of glaciers.

Table 7: Association between temperature change and change in snowline

Increase in temperature	Change in snowline		
	No change	Changed	Total
No change	23	8	31
	74.19	25.81	100.00
	62.16	12.70	31.00
Increased	14	55	69
	20.29	79.71	100.00
	37.84	87.30	69.00
Total	37	63	100
	37.00	63.00	100.00
	100.00	100.00	100.00

First row has *frequencies*; second row has *row percentages* and third row has *column percentages*
Pearson chi^2 (1) = 26.6628 pr = 0.000
Likelihood-ratio chi^2 (1) = 26.7813 pr = 0.000
Source: Computed by the authors on STATA 13.0, based on field survey, 2021

Table 8: Association between temperature and precipitation

Change in temperature	Change in Precipitation		
	No change	Changed	Total
	No change	Increased	Total
No change	23	8	31
	74.19	25.81	100.00
	46.00	16.00	31.00
Increased	27	42	69
	39.13	60.87	100.00
	54.00	84.00	69.00
Total	50	50	100
	50.00	50.00	100.00
	100.00	100.00	100.00

First row has *frequencies*; second row has *row percentages* and third row has *column percentages*
Pearson chi^2 (1) = 10.5189 pr = 0.001
Likelihood-ratio chi^2 (1) = 10.8588 pr = 0.001
Source: Computed by the authors on STATA 13.0, based on field survey, 2021

Similar relationship can be seen between temperature change and changes to the snowline (Table 7). A majority (63%) of the respondents felt that the snowline is changing. This proportion was far more (79.71%) among those who believed in rising temperature over the years. The statistical analysis shows a very strong relationship between the increase in temperature and the change in snowline. Significantly nearly 13 percent respondents, who did feel a change in snowline is indeed taking place, did not attribute the phenomenon to changes in temperature.

Table 9: Precipitation variation and its impact on the lives of local people.

Change in Precipitation	Impact on local people			
	No effect	Condition improved	Condition deteriorated	Total
No change	21	15	14	50
	42.00	30.00	28.00	100.00
	72.41	46.88	35.90	50.00
Increased	8	17	25	50
	16.00	34.00	50.00	100.00
	27.59	53.13	64.10	50.00
Total	29	32	39	100
	29.00	32.00	39.00	100.00
	100.00	100.00	100.00	100.00

First row has *frequencies*; second row has *row percentages* and third row has *column percentages*
Pearson chi^2 (2) = 9.0552 pr = 0.011
Likelihood-ratio chi^2 (2) = 9.3105 pr = 0.010
Source: Computed by the authors on STATA 13.0, based on field survey, 2021

Table 10: Impact of temperature on the lives of local people

Change in temperature	Impact on local people			
	No effect	Condition improved	Condition deteriorated	Total
No change	15	8	8	31
	48.39	25.81	25.81	100.00
	51.72	25.00	20.51	31.00
Increased	14	24	31	69
	20.29	34.78	44.93	100.00
	48.28	75.00	79.49	69.00
Total	29	32	39	100
	29.00	32.00	39.00	100.00
	100.00	100.00	100.00	100.00

First row has *frequencies*; second row has *row percentages* and third row has *column percentages*
Pearson chi^2 (2) = 8.3667 pr = 0.015
Likelihood-ratio chi^2 (2) = 8.0831 pr = 0.018
Source: Computed by the authors on STATA 13.0, based on field survey, 2021

Table 8 reveals highly significant association between temperature and rainfall and shows a very strong relationship between increasing temperature and increase in rainfall. An overwhelming 84 percent respondents believed increase in precipitation over the years and attributed it to increase in temperature. About 39 percent of those respondents who felt that there is an increase in temperature stated that they did not experience any change in precipitation over the years. On the contrary, a quarter of the

Table 11: Impact of snowfall

Anthropogenic perception on snowfall	Impact on local people			
	No effect	Condition improved	Condition deteriorated	Total
No change	16	13	12	41
	39.02	31.71	29.27	100.00
	55.17	40.63	30.77	41.00
Increasing	10	7	8	25
	40.00	28.00	32.00	100.00
	34.48	21.88	20.51	25.00
Decreasing	3	12	19	34
	8.82	35.29	55.88	100.00
	10.34	37.50	48.72	34.00
Total	29	32	39	100
	29.00	32.00	39.00	100.00
	100.00	100.00	100.00	100.00

First row has *frequencies*; second row has *row percentages* and third row has *column percentages*
Pearson chi^2 (4) = 11.2724 pr = 0.024
Likelihood-ratio chi^2 (4) = 12.6497 pr = 0.013
Source: Computed by the authors on STATA 13.0, based on field survey, 2021

respondents believing in stable temperature over the years found increasing precipitation taking place in the recent past. The likelihood ratio p-value is 0.001 showing strong association between increase in temperature and an increase in rainfall.

The effect of precipitation change is perceived to be most vital as far its impact on the livelihood of the people (Table 9). Overall, 53.13 percent people whose condition has improved attributed it to increase in precipitation while 64.10 percent of those who experienced deterioration in their condition too attributed it to increase in temperature. Nearly 28 percent respondents who experienced no effect on them attributed it to increase in temperature. Around 36 percent respondents among those who experienced no change in precipitation, stated to have their condition deteriorated over the years due to socio-economic and demographic reasons.

Table 10 reveals that more (44.93%) respondents perceived a deterioration in their conditions compared to fewer of them (34.78%) who found themselves benefitting from rising temperature. A majority of the respondents (79.49%) who experienced to have their condition deteriorated over the years attributed it to increase in temperature while an equal proportion (75%) who said to have their condition improved attributed it to the same factor. The responses are evident of the fact that the effect of temperature changes has not been uniform among the inhabitants. This is understandable as the affected people are not homogenous and only proves that the effects of natural hazards are unequally distributed among the people who are socially and economically differentiated. Interestingly

Table 12: Logistic regression for change in snowline

change snowline	coef.	St. Err.	t-value	p-value	[95 per cent conf	interval]	sig
Precipitation	-1.284	0.625	-2.06	0.04	-2.508	-0.059	**
Melting glacier	1.868	0.572	3.27	0.001	0.747	2.989	***
Temperature	2.423	0.599	4.04	0	1.249	3.597	***
Constant	-1.954	0.593	-3.29	0.001	-3.116	-0.791	***
Mean dependent var	0.630		Sd dependent var		0.485		
Pseudo r-squared	0.337		Number of obs		100.000		
Chi-square	44.469		Prob > chi²		0.000		
Akaike crit. (aic)	95.322		Bayesian crit. (Bic)		105.743		

**** p<0.01, ** p<0.05, * p<0.1*

Source: Computed by the authors on STATA 13.0, based on field survey, 2021

a fifth of the respondents felt their conditions have deteriorated regardless of changes in temperature.

In all, about 41, 25 and 34 percent respondents experienced no change, increasing and decreasing snowfall over the years respectively. Table 11 shows nearly 56 percent people who experienced decreasing snowfall induced by anthropogenic activities, have their lives deteriorated over the years. However, 28 percent respondents stated to have experienced an increase in snowfall, but also have their condition improved over the years. The Pearson chi-square p-value for the association between the snowfall and its impact on the local inhabitants is 0.024. It is statistically highly significant showing a strong relationship between the snowfall and its impact on the local people. The likelihood ratio p-value 0.013 shows a very strong relation between perceived anthropogenic impact of snowfall and impact on local people.

Regression model analysis

Based on the primary survey-based perception study of the local inhabitants on the impact of climate change on livelihood in cryosphere region, regression models were run to see the relationship of explanatory variables on outcome variables. In order to assess the change in snowline as an outcome and its relationship with the explanatory variables in the study area, logistic regression model with the coefficient and p-value were used to examine the association (Table 12). Snowline depends on factors like temperature, melting of glaciers, precipitation etc. Table 12 shows the coefficient of snowline change using 3 factors and it was found that the coefficient between precipitation and snowline is negative. There is an inverse relationship between change in precipitation and the change in snow line, i.e. 1 per cent change in the precipitation would bring -1.284 percent changes in the snowline when all factors mentioned in the model work together. The coefficient of melting of glaciers shows positive relation with snowline. The 1-point change in it would bring 1.868 times change in snowline when all factors mentioned in the model work together. The temperature also has a positive relationship with the snowline i.e. 1-point change would bring a change

Table 13: Logistic Regression for altitudinal change of vegetation

Altitudinal change in vegetation	coef.	St. Err.	t-value	p-value	95% conf.	interval	significance
Precipitation	4.026	1.572	2.56	0.01	0.945	7.108	**
Change snowline	5.624	1.307	4.30	0	3.061	8.186	***
Tree line changed	0.533	0.526	1.01	0.312	-0.499	1.565	
Snowfall	-1.14	0.601	-1.90	0.058	-2.319	0.038	*
Temperature	0.924	0.533	1.73	0.083	-0.121	1.97	*
Constant	-4.121	1.234	-3.34	0.001	-6.541	-1.702	***
Mean dependent var	0.580		Sd dependent var		0.496		
Pseudo r-squared	0.560		Number of obs		100.000		
Chi-square	76.227		Prob > chi2		0.000		
Akaike crit. (aic)	71.831		Bayesian crit. (Bic)		87.462		

**** p<0.01, ** p<0.05, * p<0.1*

Source: Computed by the authors on STATA 13.0, based on field survey, 2021

of 2.423 times in the snowline, conditioned to all factors work simultaneously. Both melting of glaciers and temperature are directly proportional to the changes in the snowline. The p-value of precipitation for change in snowline is significant at 0.05 which is significant at 95 per cent level of confidence. The melting of glaciers and that of temperature are significantly associated at 0.001 p-value. As all these p-values are less than the significance level, and are statistically significant in their relation between the dependent and independent variables. Melting of glaciers and temperature are perceived to be the most prevalent factors to bring any change in snowline and are directly proportional to it.

The coefficient relation between precipitation and altitudinal change of vegetation is found to be positive and 1-point change in precipitation brings 4.026 times change in altitudinal change to vegetation. The relationship between snowline change and altitudinal vegetation change are very strongly and positively associated, e.g. a 1-point change in snowline change brings 5.624 times changes in altitudinal change in vegetation, which is the highest among all the explanatory factors when they work together. Temperature has a positive relation wherein 1-point change in temperature is likely to bring 0.924 times changes in altitudinal change of vegetation in a combined model. Change in snowline is significant at 0.001 which has 99 per cent confident interval. Since all these p-value are less than the significance level, there are statistically significant relationship between the dependent and independent variables (Table 13).

Coping with change

Cryosphere change poses threat as well as offer an opportunity to the local people. One of the threats has been shortage of water; the other refers to enhanced frequency and intensity of natural hazards- both adversely affecting the life and livelihood of the inhabitants. People living in the fragile mountainous region are highly vulnerable to even minor changes in environmental conditions (Messerli & Ives, 1997). The region has experienced irregularities in the frequency and intensity of rainfall and snowfall (Dimri et al., 2021). The peak rainy season commence around June and has now shifted to the third week of July (Joshi et al., 2015). Incidence of more dry and irregular spells of rainfall has aggravated water scarcity and has been responsible for lowering agricultural productivity. These dry spells are the season of great hardships for women as they have to travel large long distances to fetch water (Beniston, 2003; Joshi et al., 2015). Traditional cropping pattern is coming under stress as a direct outcome of cryosphere change which is also witnessing greater frequency of crop failure, decrease in the crop yield, fodder and reduction in livestock production (Joshi et al., 2015). The fluctuation in precipitation and temperature has increased the incidence of disease in crops and failure of crops (Semwal et al., 2004; Negi, 2012). Locals engaged in traditional farming have shifted to other commercial crops such and mustard, peas, potato, onion and other horticulture like apple, walnuts, pears (Mittal et al., 2008). Changes can be seen in the cropping pattern of high-value crops. There has been an increase in the horticulture sector. The economy in the mountainous region of Uttarkashi also depends on livestock. However, the dependence of people on livestock for livelihood is gradually declining (Jodha, 1992). The assets such as livestock are extremely limited even among the people who were once fully dependent on them. Rural households keep a lesser number of animals in comparison to the past. Also, raising livestock proves expensive for them as it does not give them desired income. Due to all these, there is a continuous out-migration towards the plains (Mamgain & Reddy, 2017). The tourism sector has a great potential for the new generation for livelihood in Uttarkashi. The youth of the district see huge scope in employment in tourism industry if expanded properly. Accelerated tourism in the last few decades have greatly reduced dependence of people on agricultural and traditional livelihood practices (Rasul & Molden, 2015). With the changes in weather and climate, the local community has shown resilience through adaptation strategies based on indigenous culture, knowledge and belief by growing traditional crops, mixed farming, relying more on traditional mode of irrigation, sustainable tourism, etc. (Joshi et al., 2015).

Conclusion

The fluctuations and changes in climatic parameters in this cryosphere region in the recent times, as perceived by the inhabitants, have had significant impacts on their life and livelihood, particularly agriculture practiced by a majority of the marginal farmers small farmers. Natural calamity constitutes a major concern that affects agricultural output. Even small changes in the cryosphere have an immediate impact on the livelihood options available to the people living in these regions. Regression models reveal that there is a significant and strong relationship between change in snowfall to temperature and altitudinal change in vegetation to precipitation and snowline change. A majority of the inhabitants reported fluctuations in the climatic parameters impacting their livelihood patterns over the years leading to deterioration in their conditions. However, they are making resilient efforts to combat these changes by adopting new strategies like extension of agricultural services, diversifying high-value crops instead of intensive ones, developing farms and increasing access to markets, expanding rural tourism development, connectivity of roads, etc. There has been improvement in recent years in infrastructure which provides them with an opportunity to diversify their livelihood. Tourism is considered by them as a viable option under such conditions apart from switching over to horticulture.

Perception of the threat varies significantly with regard to the responses to many parameters of change in the cryosphere and is often highly contrasting. These contradictory responses are due to their varying socio-economic position as regards their landholding status, occupation, income, caste and class etc. and which fashion their perception. The perceived effects of natural hazards are unequally distributed among the people who are socially and economically differentiated. The present study has not taken this aspect as part of its focus which can be undertaken as a future study that may unravel the underlying social and economic factors that has significant bearing on their perception.

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