Annual Progress Report 2022-23

State Centre on Climate Change

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ANNUAL PROGRESS REPORT 2022-23

SNOW & GLACIERS STUDIES

1. ASSESSMENT OF SPATIAL DISTRIBUTION OF SEASONAL SNOW COVER DURING THE YEAR 2022-23 IN HIMACHAL PRDAESH USING AWIFS SATELLITE DATA

SEASONAL SNOW COVER VARIATIONS IN HIMACHAL DURING 2022-23 AND ITS COMPARATIVE ANALYSIS WITH REFERENCE TO 2021-22

INTRODUCTION

The State of Himachal Pradesh receives winter precipitation in the form of snow at the higher altitudes. About 1/3rd of the total geographical area of the State remains under thick snow cover during the winter season. Most of the major rivers like Chenab, Beas, Parvati, Baspa, Spiti, Ravi, Satluj and their perennial tributaries originating from the Himalayas depend upon the seasonal snow cover for their discharge dependability. Besides this, the snow cover also helps in controlling the accumulation and ablation patterns of the glaciated regions in the State.

Considering the importance of seasonal snow cover as a major input in controlling the hydrology of the river basins, seasonal snow cover assessment in terms of its spatial distribution is being carried out in different river basins in Himachal Pradesh during the winter season from October to April. In order to assess the spatial extent of seasonal snow cover in Himachal Pradesh during the winters of 2022-23, and its comparative analysis with that of 2021-22, the total area under snow cover was estimated using AWIFS satellite data during 2022-23 and was compared with that of the values estimated during the period 2021-22 in Himachal Pradesh.

RESULTS AND DISCUSSION

Snow is an essential resource present in the Himalyas. Therefore, monitoring of snowfall changes over a time period is important for hydrological and climatological purposes. Considering the present trend of winter snowfall in Himachal Pradesh, the winter precipitation was mapped in all the basins viz Chenab, Beas, Ravi and Satluj Basins in H.P. using AWIFS satellite data having spatial resolution of 56 mts w.e.f October 2022 to Apri 2023. During 2022-23, snowfall was estimated and analyzed with reference to the averaged value of the total area under snow cover in each month from October to April using the following sets of available AWIFS data.

Table 1 AWIFS Satellite data used

Sr. No.	Path/Row	Sensor	Date of Pass
1.	99/48	R2/AWiFS	06-10-2022
2.	96/49	R2/AWiFS	15-10-2022
3.	98/49	R2/AWiFS	25-10-2022
4.	96/48	R2/AWiFS	27-10-2022
5.	99/49	R2/AWiFS	30-10-2022
6.	95/49	R2/AWiFS	03-11-2022
7.	96/48	R2/AWiFS	08-11-2022
8.	97/49	R2/AWiFS	13-11-2022
9.	98/50	R2/AWiFS	18-11-2022
10.	94/49	R2/AWiFS	22-11-2022
11.	98/49	R2/AWiFS	23-11-2022
12.	97/47	R2/AWiFS	25-11-2022
13.	100/49	R2/AWiFS	28-11-2022
14.	98/47	R2/AWiFS	30-11-2022
15.	97/49	R2/AWiFS	07-12-2022
16.	98/48	R2/AWiFS	12-12-2022
17.	95/45 & 94/50	R2/AWiFS	16-12-2022
18.	99/49	R2/AWiFS	17-12-2022
19.	95/49	R2/AWiFS	21-12-2022
20.	100/51	R2/AWiFS	22-12-2022
21.	97/50	R2/AWiFS	31-12-2022
22.	98/50	R2/AWiFS	05-01-2023
23.	99/50	R2/AWiFS	10-01-2023
24.	95/50	R2/AWiFS	14-01-2023
25.	100/50	R2/AWiFS	15-01-2023
26.	96/51 & 96/46	R2/AWiFS	19-01-2023
27.	96/46	R2/AWiFS	31-01-2023
28.	99/49	R2/AWiFS	03-02-2023
29.	100/50	R2/AWiFS	08-02-2023
30.	97/50	R2/AWiFS	17-02-2023

31.	98/50	R2/AWiFS	22-02-2023
32.	96/46	R2/AWiFS	24-02-2023
33.	94/50	R2/AWiFS	26-02-2023
34.	99/50 & 95/50	R2/AWiFS	27-02-2023
35.	95/49	R2/AWiFS	03-03-2023
36.	96/50	R2/AWiFS	08-03-2023
37.	97/50	R2/AWiFS	13-03-2023
38.	94/49	R2/AWiFS	22-03-2023
39.	99/50	R2/AWiFS	23-03-2023
40.	95/50	R2/AWiFS	27-03-2023
41.	100/50	R2/AWiFS	28-03-2023
42.	97/49	R2/AWiFS	06-04-2023
43.	98/49	R2/AWiFS	11-04-2023
44.	94/49	R2/AWiFS	15-04-2023
45.	99/50	R2/AWiFS	16-04-2023
46.	96/50	R2/AWiFS	25-04-2023
47.	97/49	R2/AWiFS	30-04-2023

CHENAB BASIN

Chenab basin comprising of three sub basin (Chandra, Bhaga, Miyar) having total basin area (8562 Km^2) was analysed to assess the total area under snow during the year 2022-23 w.e.f. October to April. Based on the month wise avaerg analyis, it has bnee found that during 2022-23 winter, there was a negative trend in the area under snow from October to March , where as the April shows a postive trend in comaprision to 2021-22 winter. Thus as a whole, the Chenab basin during the winters of 2022-23 experience less snow cover area (7049.67 Km^2) in compariuions to 2021-22 (7357.22 Km^2) reflecting an overall decrease of about 4% in 2022-23 w.e.f October to April . Further analysis reveals that during 2022-23 winter, there was a negative trend in total area under snow cover during early winters i.e in October but slighly positive in November, where as during peak winter months i.e December to February a neagtive trend was observed in comaprison to 2021-22 winter . In April which is the beginning of the ablation season, the late snowfall has increased the area under snow in the basin and enhacnement of about 22% during April 2023 was observed in the entire Chenab basin. (Fig. 1,2 & Table 1).

Table 2 Area under snow in Chenab Basin (8562 km^2)

Name of the Basin	Observation Month	Area under Snow (Km^2) 2021-2022	Area under Snow (Km^2) 2022-2023	% Area under Snow in 2022-2023	Change in area under snow cover (%) w.r.t 2021-22
Chenab	October	7111.15	4544.44	53.08	(-)36.09
	November	6748.01	7116.32	83.12	(+)5.46
	December	7593.06	6843.02	79.92	(-)9.88
	January	7973.85	7582.3	88.56	(-)4.91
	February	**8561.66**	**8231.34**	**96.14**	**(-)3.86**
	March	7834.82	7701.42	89.95	(-)1.7
	April	5671.99	7328.86	85.59	22.52
	Avg. Total	**7357.22**	7049.671	82.33	**-4.18**

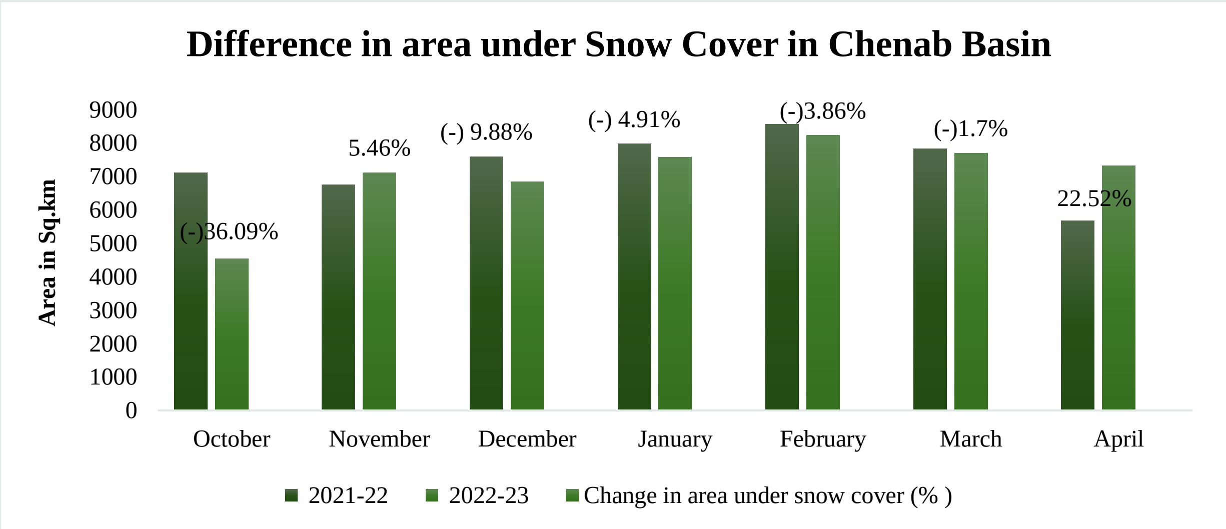


Figure 1 Difference in area under Snow cover in Chenab Basin

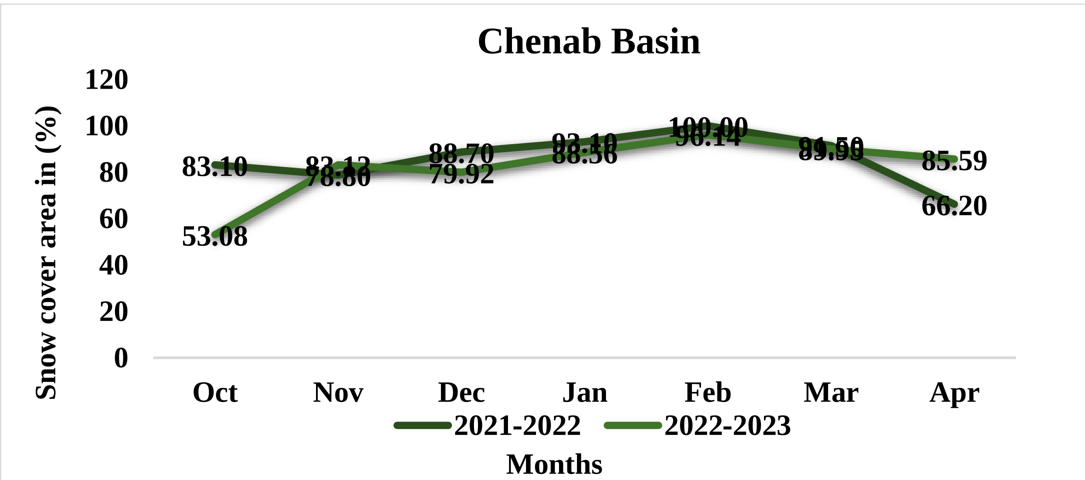


Figure 2 Area under Snow cover (%) in Chenab Basin

BEAS BASIN

The Beas basin (4350 Km^2) as a whole comprising of Upper Beas, Jiwa and Parvati sub basins has been studied for mapping area under seasonal snow during October to April (2022-23). On analysing the satellite data, it is found that the Beas basin also shows almost similar trend like that of Chenab basin, wherein the only positive trend was seen in November and the remaining months show a negative trend thereafter positive in April **(Table: 3 & Fig.: 1, 2)** with an overall reduction of 9% surface area from October April in the basin during 2022-23.

Table 3 Area under Snow in Beas Basin (4350 Km^2)

Name of the Basin	Observation Month	Area under Snow (Km^2) 2021-22	Area under Snow (Km^2) 2022-23	% Area under Snow in 2022-2023	Change in area under snow cover (%) w.r.t 2021-22
Beas	October	1612.3	1666.64	38.31	(+)3.37
	November	1566.89	1895.42	43.57	(+)20.97
	December	2587.75	1929.44	44.35	(-)25.44
	January	2871.1	2403.43	55.25	(-)16.29
	February	3890.21	2638.74	60.66	(-)32.17
	March	2606.59	2464.31	56.65	(-)5.46
	April	1605.75	2226.2	51.18	(+)38.64
	Avg. Total	**2391.49**	**2174.88**	50.00	**(-)9.06**

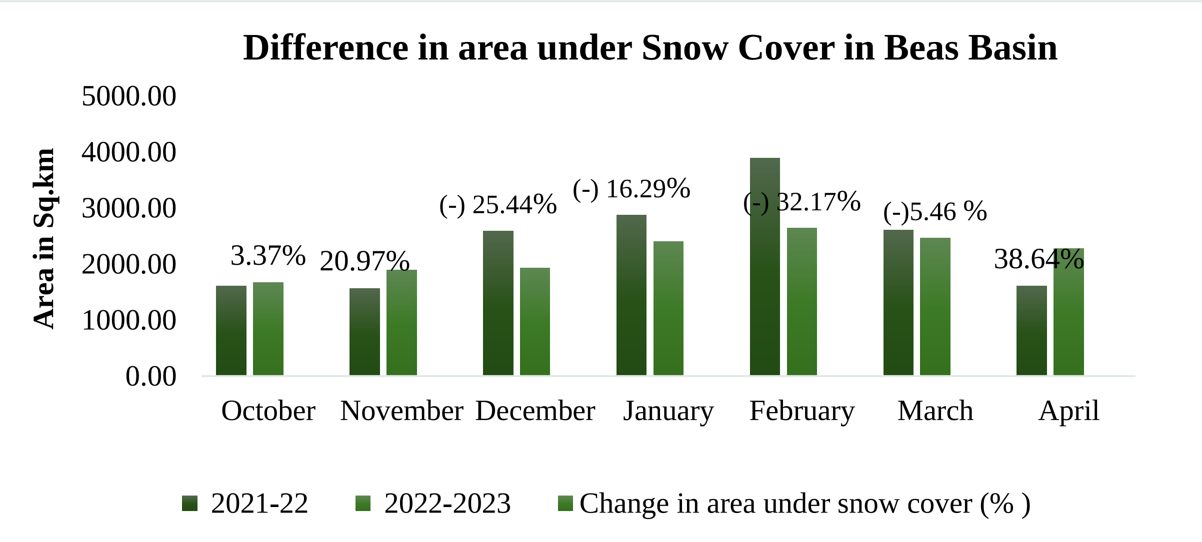


Figure 3 Difference in Area under Snow cover in Beas Basin

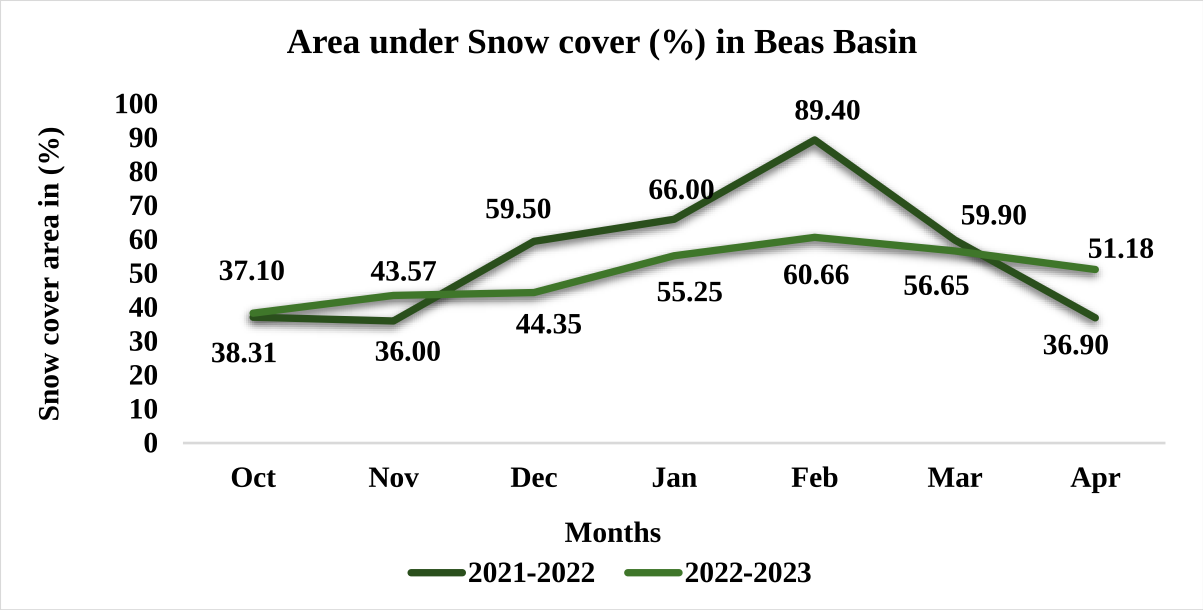


Figure 4 Area under Snow cover (%) in Beas Basin

RAVI BASIN

The Ravi basin (4907 Km^2) which is on the Southwestern side of the Pir Panjal range also shows similar trends like that of its adjoining basin on the north i.e., the Chenab basin in 2022-23. On analysing the satellite data, it is found that, the Ravi basin also shows a negative trend 2022-23 except April wherein the trend was positive with an overall reduction of about 10% in 2022-23 in comparison to 2021-22 winter (**Table-4 & Figure-5, 6).**

Table 4 Area under Snow in Ravi Basin (4907 Km^2)

Name of the Basin	Observation Month	Area under Snow (Km^2) 2021-2022	Area under Snow (Km^2) 2022-2023	% Area under Snow (2022-2023)	Change in area under snow cover (%) w.r.t 2021-22
Ravi	October	2167.18	997.65	20.33	(-)53.97
	November	1651.91	1592.87	32.46	(-)3.57
	December	2010.05	1772.36	36.12	(-)11.83
	January	2967.58	2865.29	58.39	(-)3.45
	February	2605.6	2295.91	46.79	(-)11.89
	March	2213.98	2053.53	41.85	(-)7.25
	April	1059.08	1626.46	33.15	(+) 53.57
	Avg. Total	**2096.48**	1886.296	38.44	-10.02

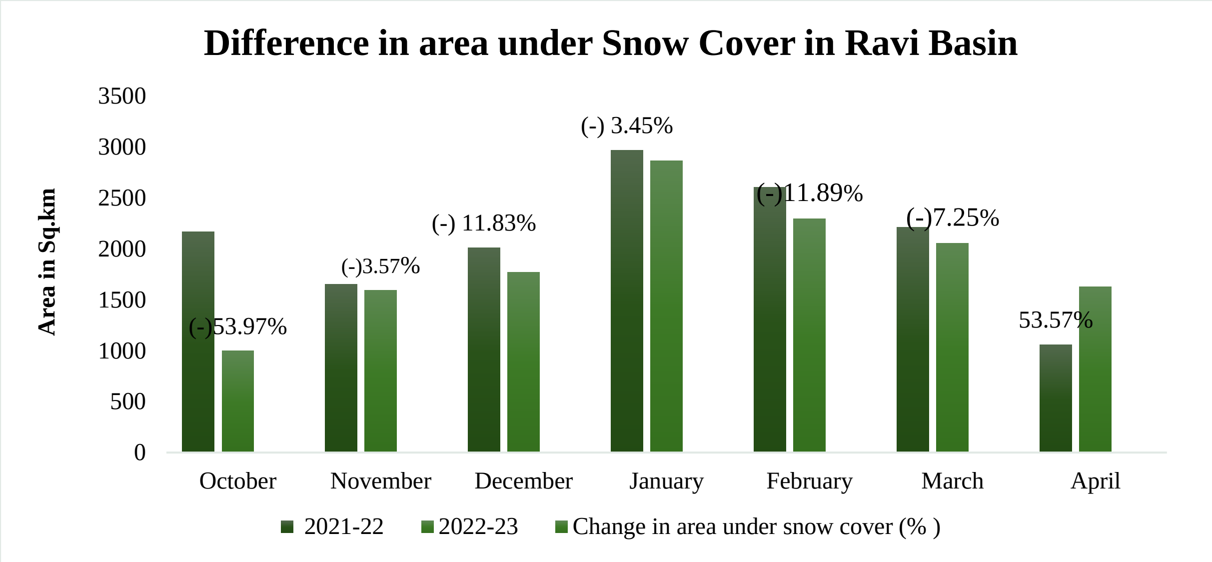


Figure 5 Difference in Area under Snow Cover (%) in Ravi Basin

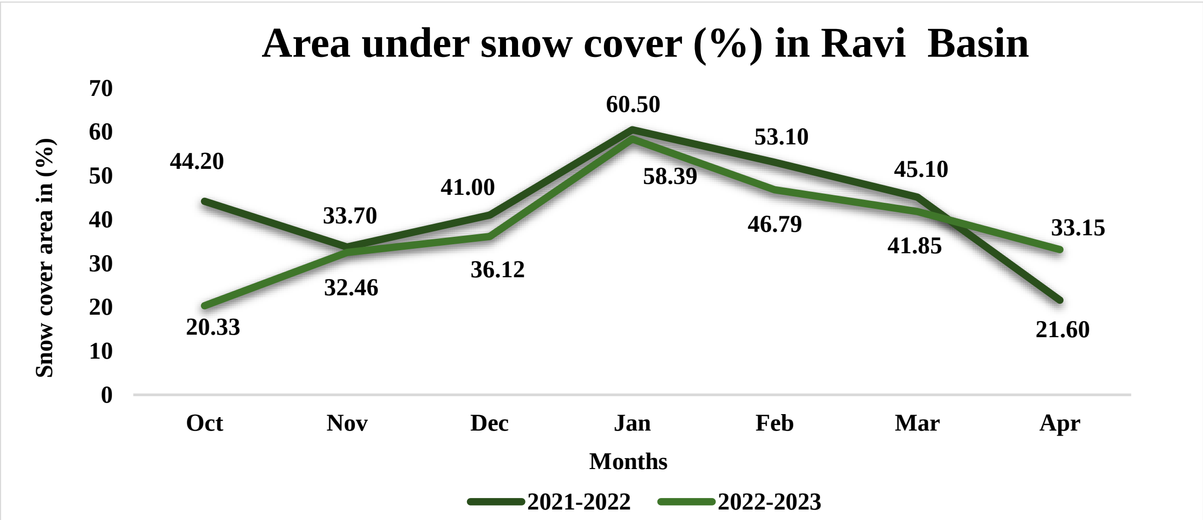


Figure 6 Area under Snow Cover (%) in Ravi Basin

SATLUJ BASIN

On the South eastern part of the State, the Satluj basin (22665 Km^2) has been studied comprising of the Spiti Basin as a whole which includes the catchment area in the Tibetan part, Baspa basin and the areas along the Satluj River downstream of Khab in Himachal Pradesh. On analysing the satellite data, the Satluj basin as a whole shows a reduction of about 22% in total average area under snow in 2022-23 in comparison to 2021-22, wherein the average snow cover has decreased from 11398.81 Km^2 (2021-22) to 8868.27 Km^2 (2022-23) respectively with negative trends in all the months except April. (Table: 5 & Fig.: 7, 8).

Table 5 Area under Snow in Satluj Basin (22665 Km^2)

Name of the Basin	Observation Month	Area under Snow (Km^2) 2021-2022	Area under Snow (Km^2) 2022-2023	% Area under Snow (2022-2023)	Change in area under snow cover (% change) w.r.t 2021-2022
Satluj	October	6926.18	5067.66	22.36	(-)26.83
	November	10001.18	7777.58	34.32	(-)22.23
	December	12304.65	5435.8	23.98	(-)55.82
	January	15211.40	9445.43	41.67	(-)37.90
	February	15922.90	13172.24	58.12	(-)17.27
	March	11869.10	11445.42	50.50	(-)3.56
	April	7556.28	9733.77	42.95	(+) 28.82
	Avg. Total	**11398.81**	**8868.271**	39.13	**-22.20**

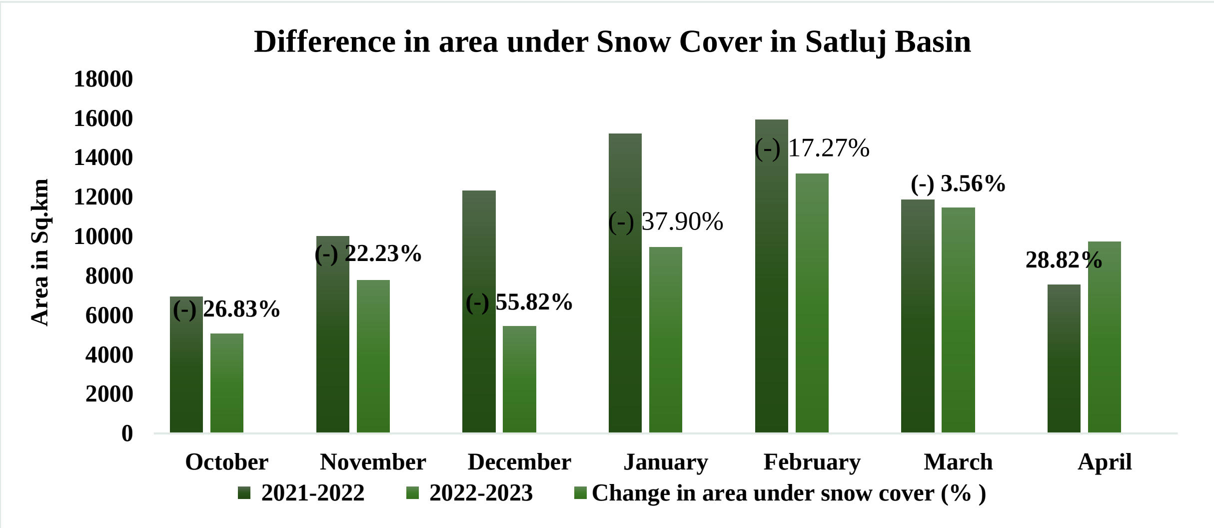


Figure 7 Difference in Area under Snow Cover in Satluj Basin

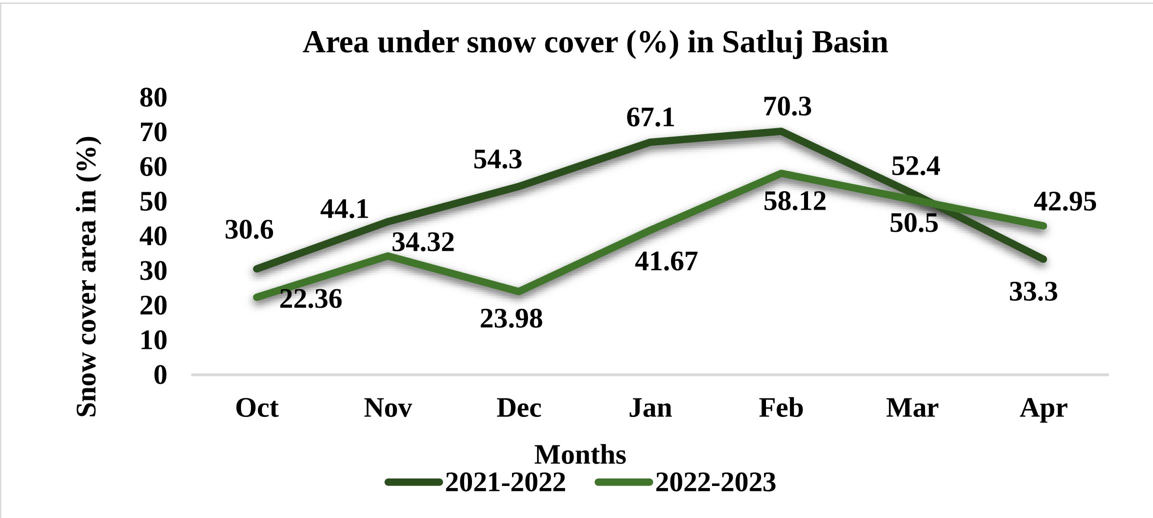


Figure 8 Area under Snow Cover (%) in Satluj Basin

BASIN WISE COMPARATIVE ANALYSIS OF AREA UNDER SNOW COVER

Table 6 Basin Wise Area under snow cover (%) in Himachal Pradesh (2022-23)

Observation Month	Chenab	Beas	Ravi	Satluj
October	53.08	38.31	20.33	22.36
November	83.12	43.57	32.46	34.32
December	79.92	44.35	36.12	23.98
January	88.56	55.25	58.39	41.67
February	96.14	60.66	46.79	58.12
March	89.95	56.65	41.85	50.5
April	85.59	51.18	33.15	42.95

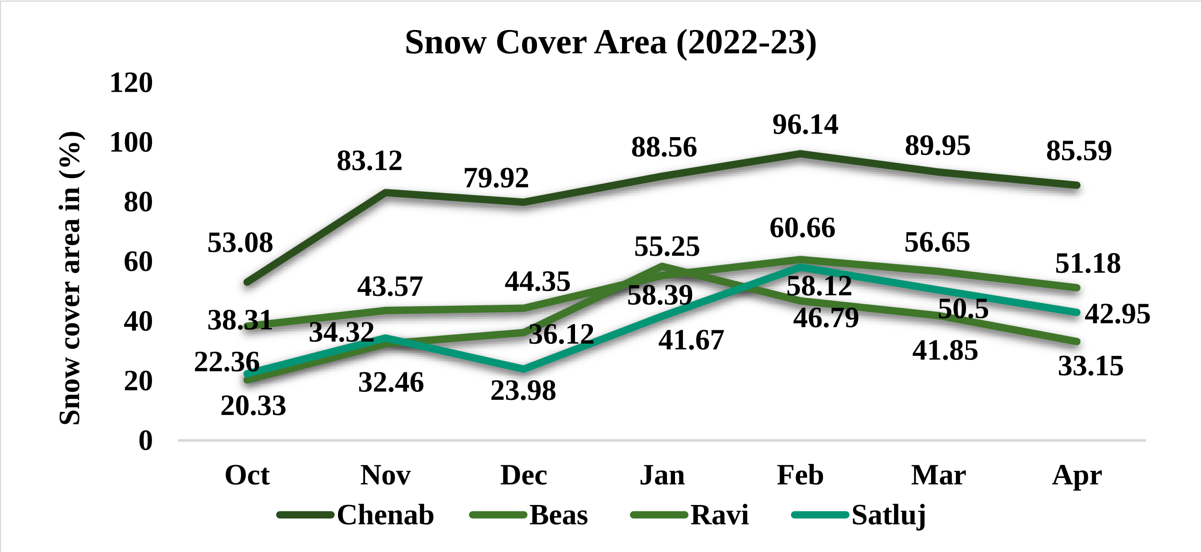


Figure 9 Basin Wise Area under Snow Cover (%) in Himachal Pradesh (2022-23)

Table 7 Area under Snow in Himachal Pradesh

Basin	**2021-2022**	**2022-2023**	**Difference in area (%)**
Chenab	**7357.22**	**7328.86**	(-)0.39
Beas	**2391.49**	**2226.20**	(-)6.91
Ravi	**2096.48**	1626.46	(-)22.42
Satluj	**11398.81**	**9733.77**	(-)14.61
Total	**23244**	20915.29	(-)10.02

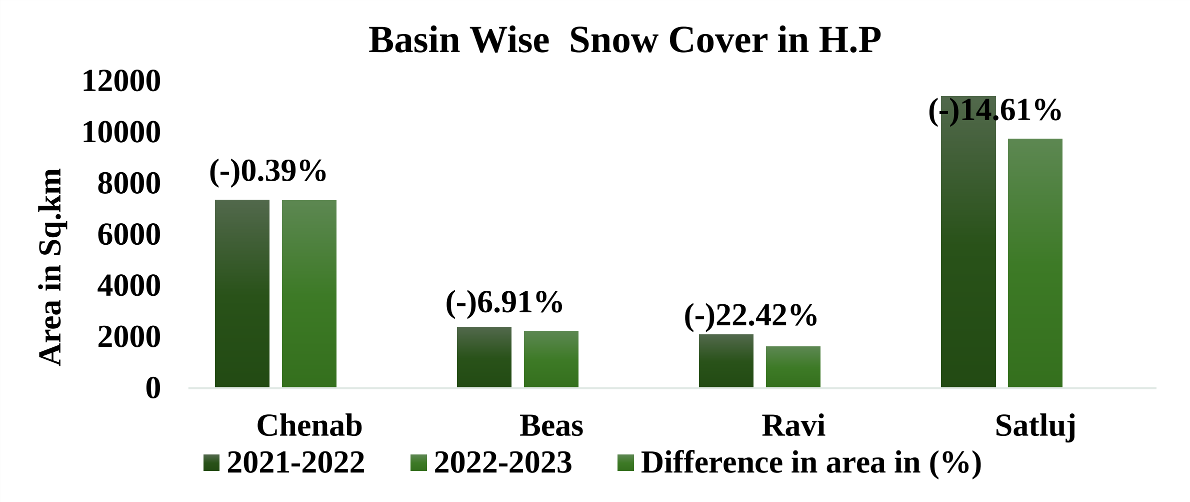


Figure 10 Basin Wise Snow Cover in H.P

Thus, based on the above analysis, it is observed that during 2021-22, there is an overall enhancement of about 19.47 % in total area under snow cover in Himachal Himalaya (Fig. 11). The analysis of Figure 3.2, reveals that all the four major rivers basins of the state i.e., Chenab, Beas, Ravi and Satluj shows an increase in the snow cover area in 2021-22 in comparison to 2020-21. The dominant enhancement in terms of the total monthly average area (Oct to April) observed in case of Ravi (24.85%), Satluj (24.83%), Beas (15.67%) and Chenab (11.85%) in 2021-22 in comparison to 2020-21 (Fig. 10 & Table-7).

Table 8 Total Area under snow in H.P

Year	2021-22 Area in km^2	2022-2023 Area in km^2	% change
Total Area	**23244**	20915.29	(-)10.02

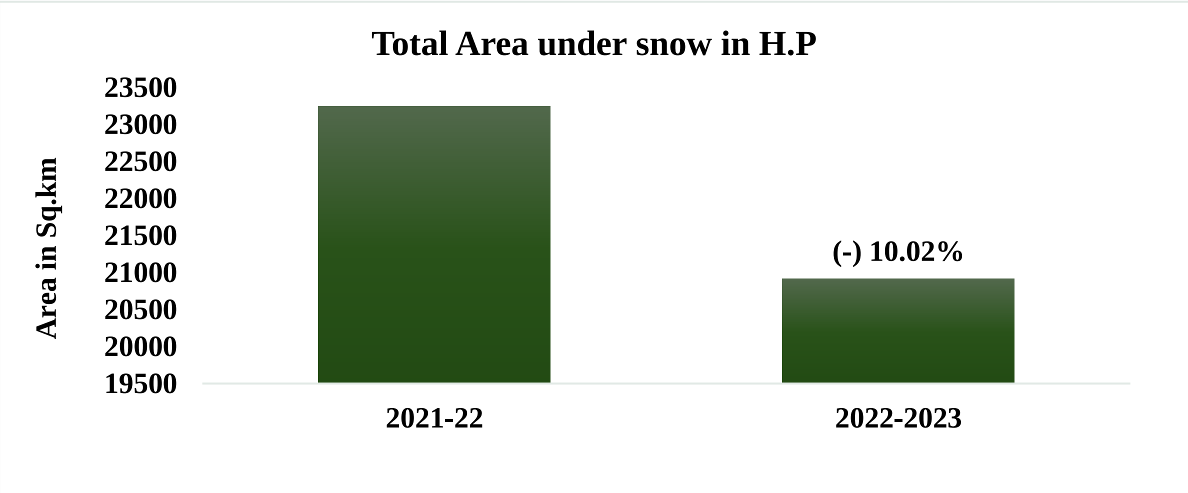


Figure 11 Total Area under Snow in H.P

TEMPERATURE TREND ANALYSIS BETWEEN 2022 & 2023 IN HIMACHAL PRADESH

Based on the temperature data collected from IMD portal for the months of October to April (2018 -23) was carried out to correlate the findings of variation of the snow cover vis-à-vis the maximum temperature in each basin. The basin was temperature trends are as under:

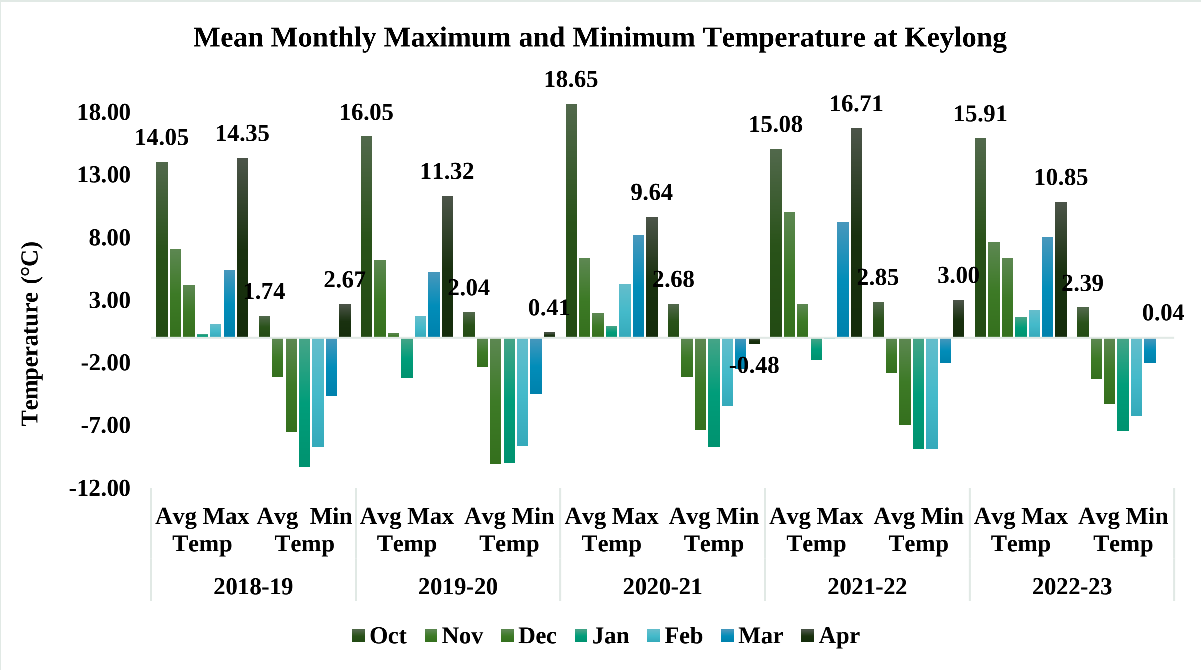


Figure 12 Mean Monthly Maximum and Minimum Temperature at Keylong (2022-2023)

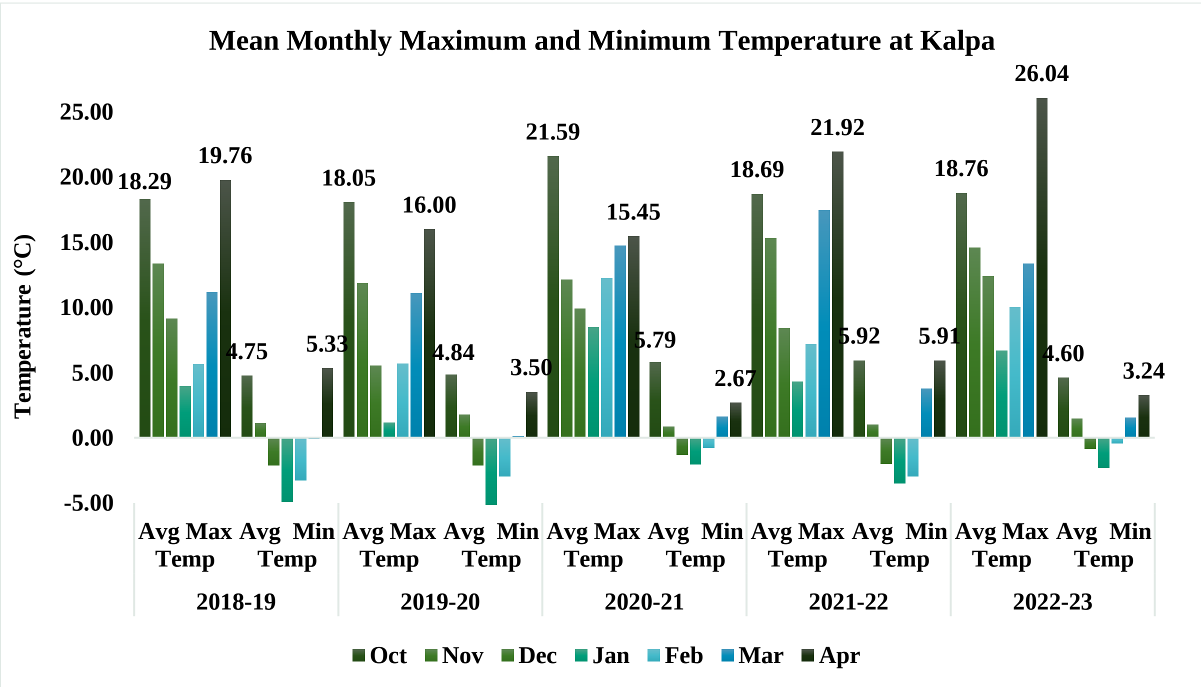


Figure 13 Mean Monthly Maximum and Minimum Temperature at Kalpa (2022-2023)

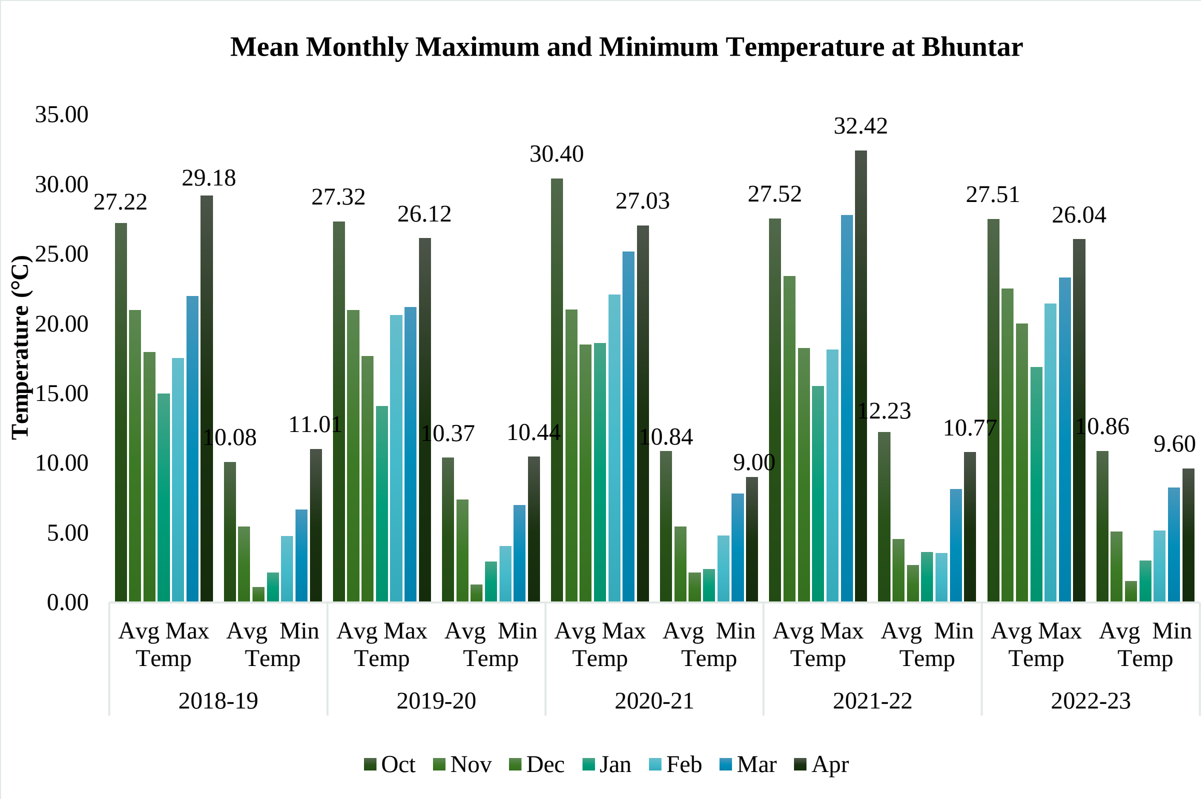


Figure 14 Mean Monthly Maximum and Minimum Temperature at Bhuntar (2022-2023)

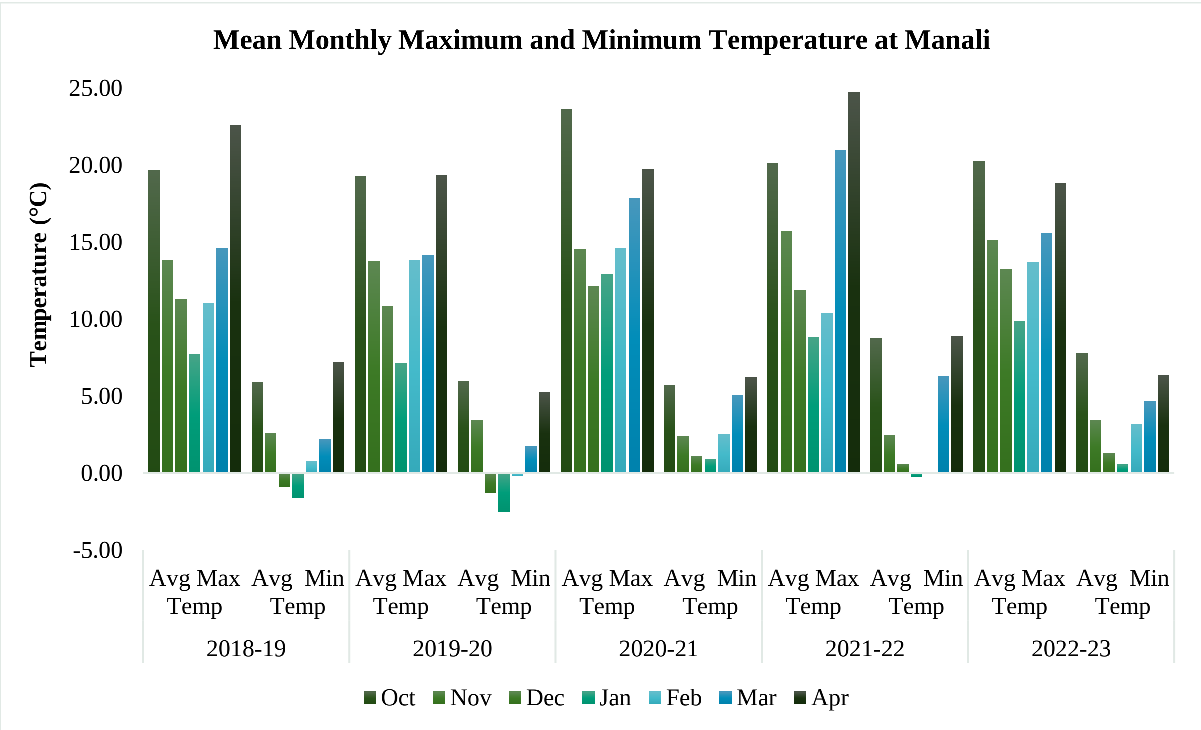


Figure 15 Mean Monthly Maximum and Minimum Temperature at Manali (2022-2023)

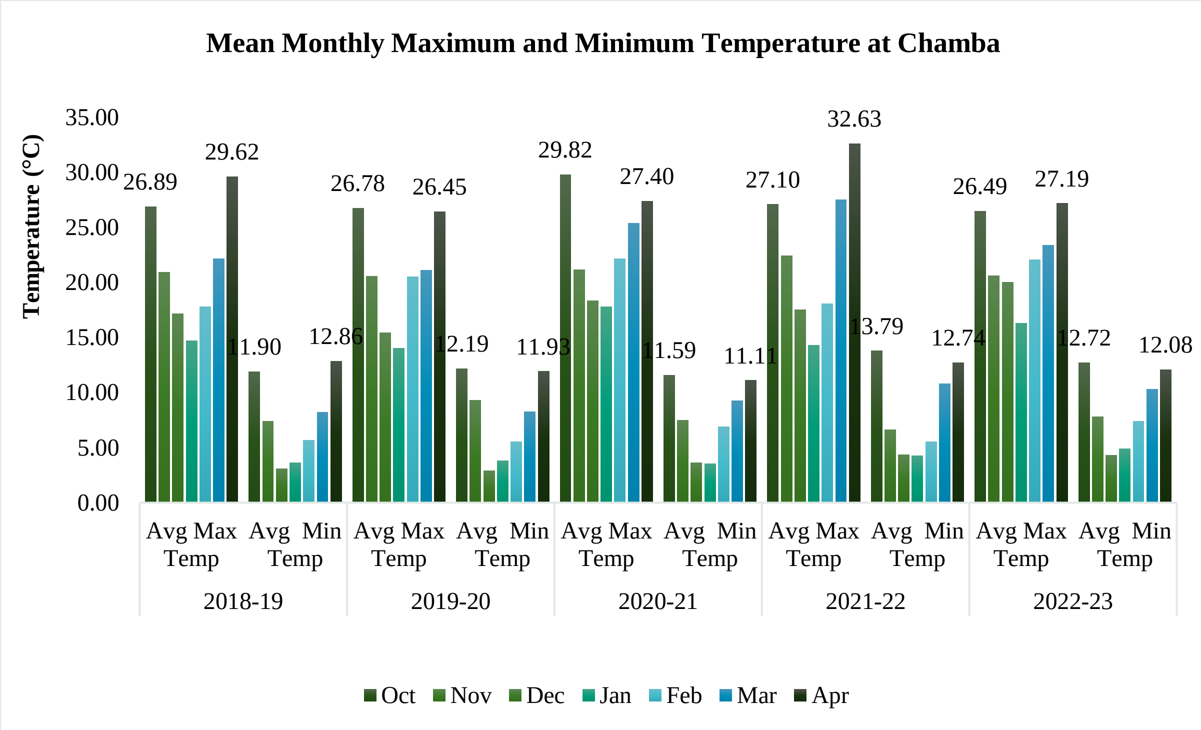


Figure 16 Mean Monthly Maximum and Minimum Temperature at Chamba (2022-2023)

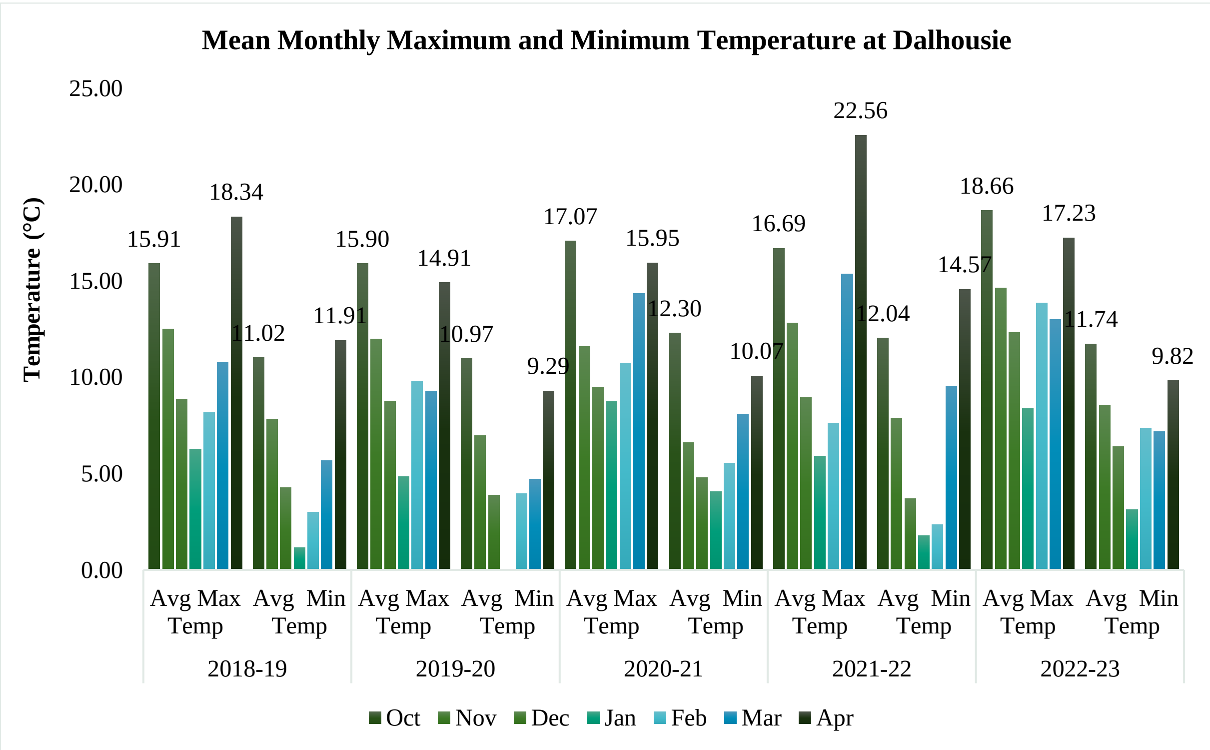


Figure 17 Mean Monthly Maximum and Minimum Temperature at Dalhousie (2022-2023)

DESCRIPTIVE ANALYSIS OF MAXIMUM AND MINIMUM TEMPERATURE

Table 9 depicts the various statistical parameters of minimum and maximum temperature for all stations such as minimum value, maximum value, mean, standard deviation, coefficient of variation (CV %), skewness and kurtosis.

Table 9 Descriptive statistics of maximum and minimum temperature of the snow accumulation months of October to April (2018-2023) for the selected stations

Stations	Variables (°C)	Minimum (°C)	Maximum (°C)	Mean	STD	CV (%)	Skewness	Kurtosis
Bhuntar	**Max Temp**	14.09	32.42	22.32	4.69	21.01	0.24	-0.80
	Min Temp	1.08	12.23	6.16	3.38	54.84	0.19	-1.30
Chamba	**Max Temp**	14.05	32.63	22.06	4.90	22.22	0.19	-0.84
	Min Temp	2.90	13.79	7.94	3.45	43.38	0.12	-1.40
Dalhousie	**Max Temp**	4.85	22.56	12.35	4.13	33.45	0.28	-0.40
	Min Temp	-0.03	14.57	6.92	3.63	52.43	0.12	-0.77
Kalpa	**Max Temp**	1.16	26.04	12.58	5.81	46.22	0.17	-0.44
	Min Temp	-5.23	5.92	0.66	3.24	490.51	0.08	-1.04
Keylong	**Max Temp**	-3.23	18.65	6.81	5.83	85.61	0.36	-0.81
	Min Temp	-10.35	3.00	-3.81	4.34	-113.67	0.15	-1.25
Manali	**Max Temp**	7.11	24.75	15.24	4.54	29.78	0.27	-0.66
	Min Temp	-2.51	8.90	3.04	3.09	101.61	0.19	-0.93

Max Temp - Maximum temperature (°C), Min Temp - Minimum temperature (°C), STD – Standard deviation, CV – Coefficient of Variation

The mean minimum value of the maximum temperature ranges from -3.23°C having mean of 6.81°C ±5.83 with the CV of 85.61% (Keylong station) to 14.09°C with the mean of 22.32°C ±4.69 and CV of 21.01% (Bhuntar station). On the other hand, mean maximum value of the maximum temperature varies from 18.65°C (Keylong station) to 32.63°C (Chamba).

The mean minimum value of the minimum temperature varies from -10.35°C having mean of -3.81°C ±4.34 (Keylong station) to 2.90°C with the mean of 7.94°C ±3.45 and CV of 43.38% (Chamba station). The mean maximum value ranges from 3.00°C (Keylong station) to 14.57°C with the mean of 6.92°C ±3.63 having CV of 52.43% (Dalhousie) in the case of minimum temperature for the snow accumulation months of October to April for the selected time period. The Keylong station has recorded negative CV of -113.67 because its mean is negative.

Skewness gives the measure of the symmetry or asymmetry of the time series dataset. As per results, skewness varied from 0.08 (Kalpa station) to 0.19 (Manali station) for the minimum temperature and 0.17 (Kalpa station) to 0.36 (Keylong station) of the maximum temperature.

Kurtosis measures the tailedness of the probability distribution and are of three types viz. mesokurtic (normal distribution), leptokurtic (fat tails) and platykurtic (thin tails). All the kurtosis values are less than zero indicating platykurtic distribution (thin tails) i.e., non-normal distribution.

TRENDS IN MAXIMUM AND MINIMUM TEMPERATURE PATTERN

In this study, ITA (innovative trend analysis) and percent bias (PBIAS) methods have been used to detect the trends of mean monthly maximum and minimum temperature for the six stations of the short time period of five years from 2018 to 2023 for only the snow accumulation months of October to April. These methods are more appropriate for detecting hidden trends in the datasets. The results of the ITA and PBIAS are presented in the figure 18 and figure 19 and table 10.

The results of the ITA and PBIAS showed an increasing trend of maximum temperature and minimum temperature for all the stations except Keylong station. This station showed an increasing trend of 0.31°C/month for the maximum temperature but for the minimum temperature decreasing trend was observed with the rate of change of -1.18°C/month. The decreasing trend of the minimum temperature at the Keylong station are in tune with the results of the work carried out by Rathore et al. (2018) for the time period from 2004 to 2018. Majority of the stations has observed non- monotonic increasing trend for the maximum and minimum temperature except Dalhousie and Manali which showed monotonic increasing trend. Dalhousie, Kalpa, Keylong and Manali stations exhibited low and medium phase of trend with no trend in the high phase for the maximum temperature. On the other hand, Bhunter and Chamba station displayed medium and high phase of increasing trend for the maximum temperature. Data points of Bhunter, Chamba and Keylong stations are spread in the low, medium and high phase for the minimum temperature. The highest PBIAS change was observed for Kalpa station with the rate of change of 22.24% and 208.84% for the maximum and minimum temperature in the second half of the series in comparison to first half of the series. The increasing trend of minimum and maximum temperature is a reflection of the global warming resulting into general increase in Earth's temperature.

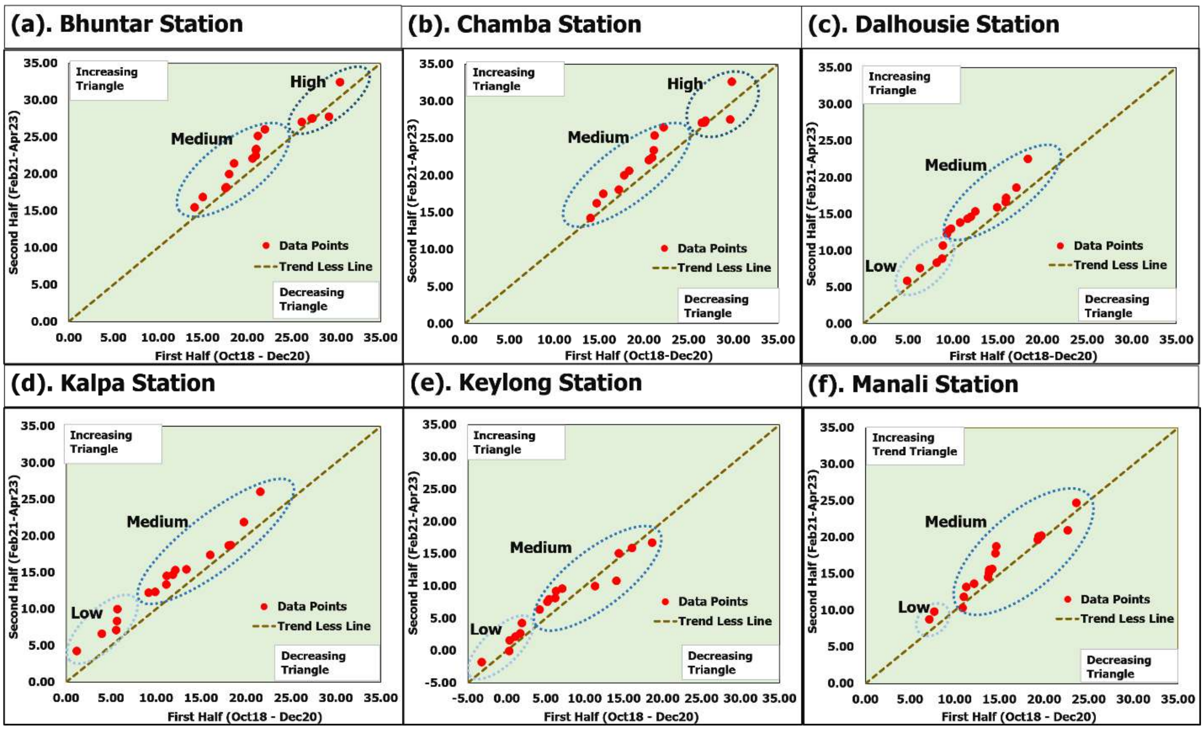


Figure 18 Mean monthly trend of maximum temperature for the snow accumulation months of October to April (2018 - 2023) using ITA method of the selected six stations

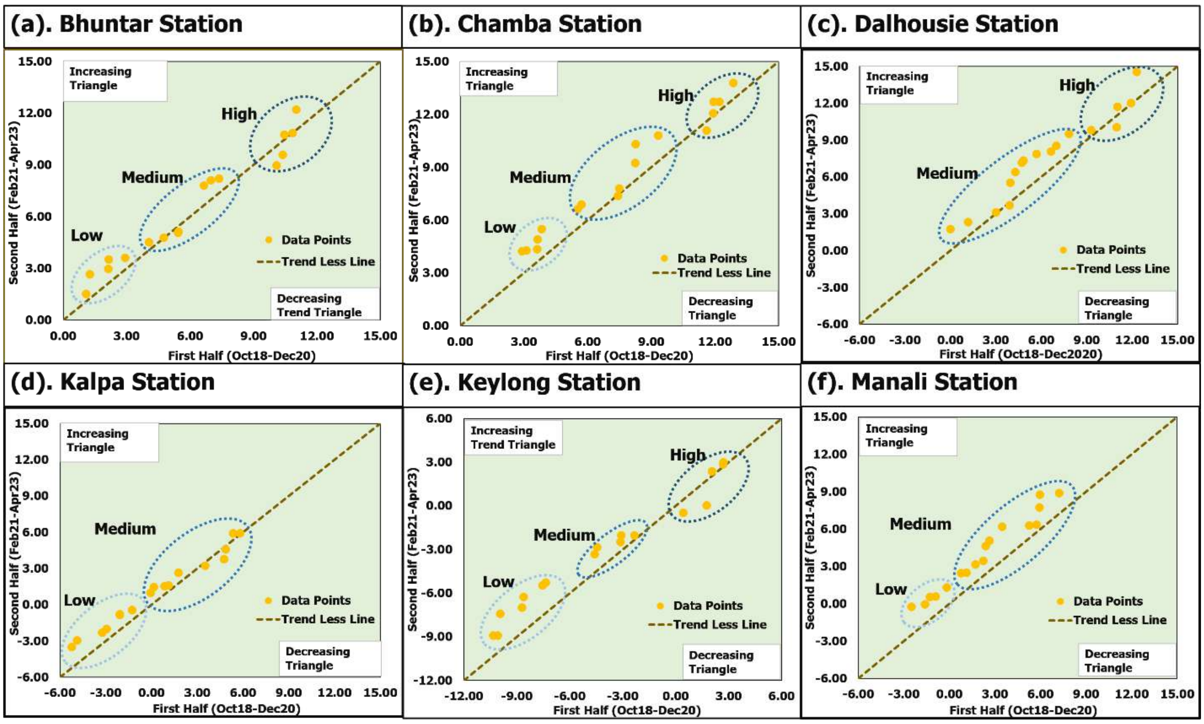


Figure 19 Mean monthly trend of minimum temperature for the snow accumulation months of October to April (2018 - 2023) using ITA method of the selected six stations

Table 10 Details of mean monthly trend of maximum and minimum temperature for the selected six stations

Stations	Variables	Slope IT (°C/month)	PBIAS	ITD
Bhuntar	Max Temp	0.37	7.43	¿
	Min Temp	0.37	7.40	¿
Chamba	Max Temp	0.37	7.47	¿
	Min Temp	0.60	11.95	¿
Dalhousie	Max Temp	0.69	17.78	¿
	Min Temp	0.99	19.77	¿
Kalpa	Max Temp	0.87	22.24	¿
	Min Temp	0.09	208.84	¿
Keylong	Max Temp	0.31	14.15	¿
	Min Temp	-1.18	-23.62	À
Manali	Max Temp	0.44	8.80	¿
	Min Temp	3.97	79.47	¿

IT – Innovative trend, PBIAS – Percent bias, ITD – Innovative trend detection ¿ - Increasing trend, À – Decreasing trend

CONCLUDING REMARKS

Based on the analysis carried out, it is concluded that in 2022 -23 winter period (Oct-April) an overall decrease in the spatial distribution of the snow cover area of the order of 10.02% was observed in comparison to the total area under snow in 2021-22 winter period, which was about 19.47% more during 2021-22 in comparison to 2020-21. Further during 2022-23, there was early snow fall in the month of October & November, there by leading to have positive trends in in some basins. During peak winter months (December-February), all the four basins i.e., Chenab, Beas, Ravi and Satluj have negative trends in comparison to last winter period and the worst affected basins were Ravi and Satluj, whereas the Chenab and Beas have comparatively better results. At the beginning of summer ablation period i.e., in April, a sudden rise in the area under snow in all the four basins thereby reflecting the only positive trend during 2022-23 winter period mainly due to late precipitation over the Himalayan region. As a whole, the Chenab basins reflects comparatively better results and there was a marginal decline in the area under snow whereas the Satluj, Ravi and Beas show a considerable reduction in the area under snow during 2022-23. This may be due to the topographic location of the Chenab basin, as the WDs originating from the Mediterranean region enters through Afghanistan, Pakistan, Jammu

Kashmir and then Himachal giving more precipitation in the Lahaul Spiti area before crossing the Pir Panjal Range controlling the western disturbance in other basins in the State.

Based on the plotting of the temperature data from 2018-23 for mean maximum and minimum temperature analysis based on Innovative Trend Analysis (ITA) and percent bias (PBIAS) methods, the analysis showed an increasing trend of maximum and minimum temperature during the period for all stations except Keylong. Thus, to conclude, the total area under snow during 2022-23 (Oct-April) was slight increase in early half i.e., October & November in some basins, whereas the peak winter (December –February) shows drastic reduction in the area under snow and the worst affected basins were the Satluj, Ravi, and Beas, whereas the Chenab was comparatively better. The late snowfall that extended to April this year, has resulted in the increase in the area under snow, but the snowfall during this period may not be much useful as the rising temperature from April onwards may enhance the melting rate there by affecting the discharge dependability of the major rivers like Beas, Chenab, Satluj and Ravi that depends upon the seasonal snow cover besides the glacier melt during the peak summer time.

2. CRYOSPHERE, SCIENCE & APPLICATION PROGRAM (CAP), SAC AHMEDABAD

The study of Himalayan Cryosphere under Cryosphere, Science & Application Program (CAP) is a collaborative study with SAC Ahmedabad. The satellite data was procured from SAC, Ahmedabad.

OBJECTIVES

1. To carry out inventory of Glaciers of Chenab and Satluj basins at 1:25,000 scale using IRS LISS III data/ Landsat ETM+ DATA/ Sentinel optical data.
2. To carry out change detection of glaciers at 1:10000 scale using high resolution data of sample glaciers.
3. To carry out Ground truth of glaciers corresponding to high resolution data.
4. Study of Spatio-temporal variability of glacier changes with respect to glacier and climate parameters.

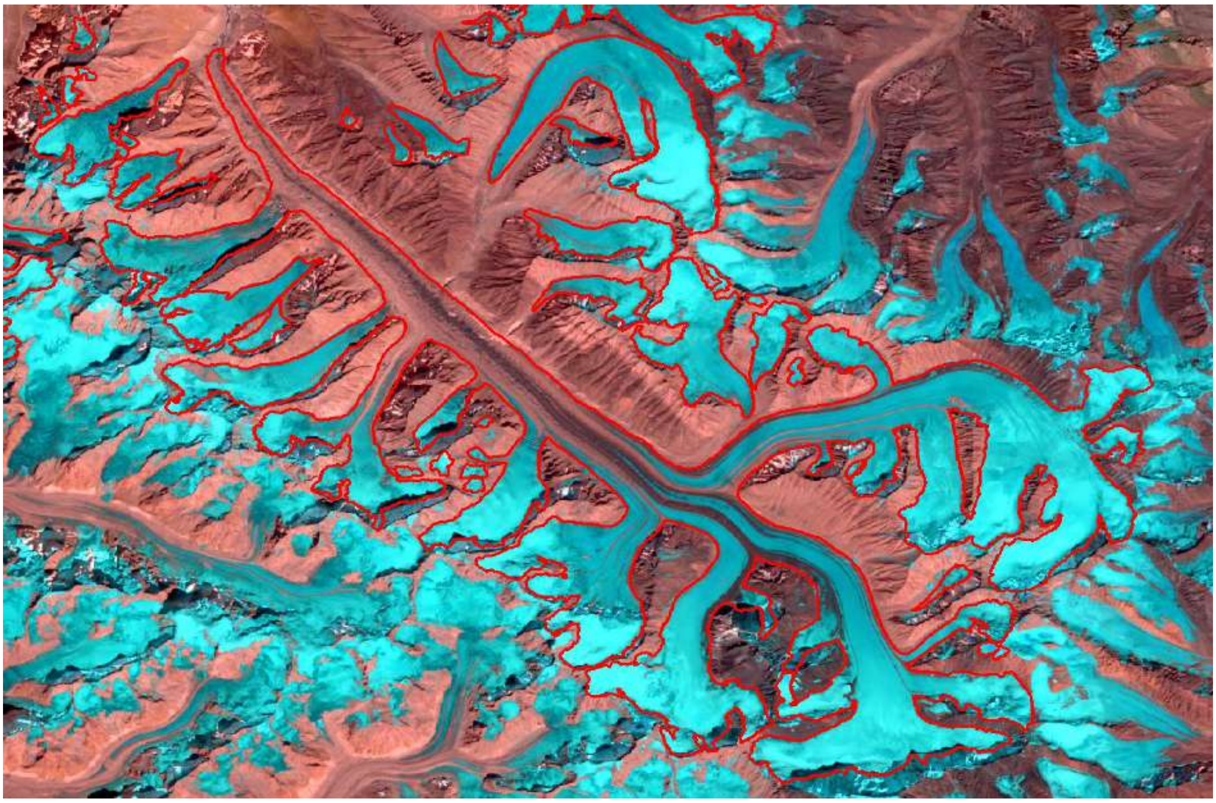


Figure 20 Bara Shigri glacier, Chenab Basin

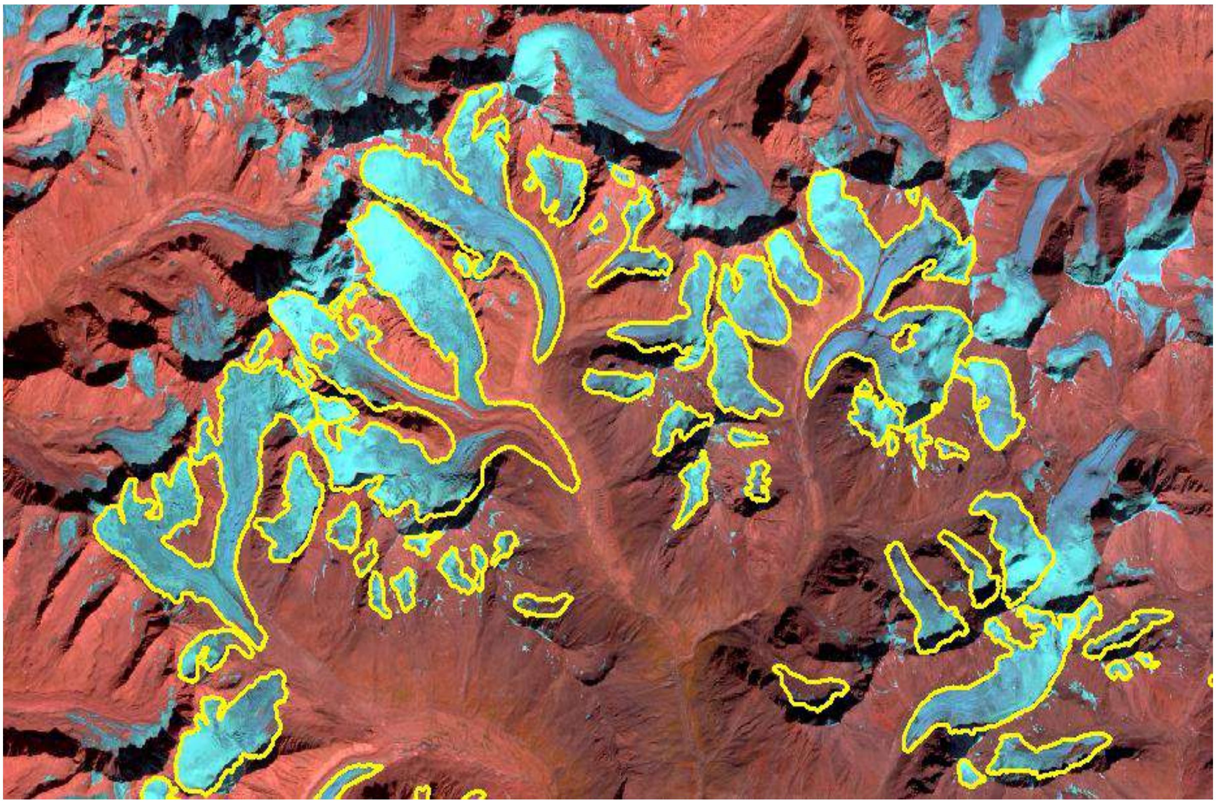


Figure 21 Glaciers of Chenab Basin

Figure 22 Samudri tapu Glacier, Chenab Basin

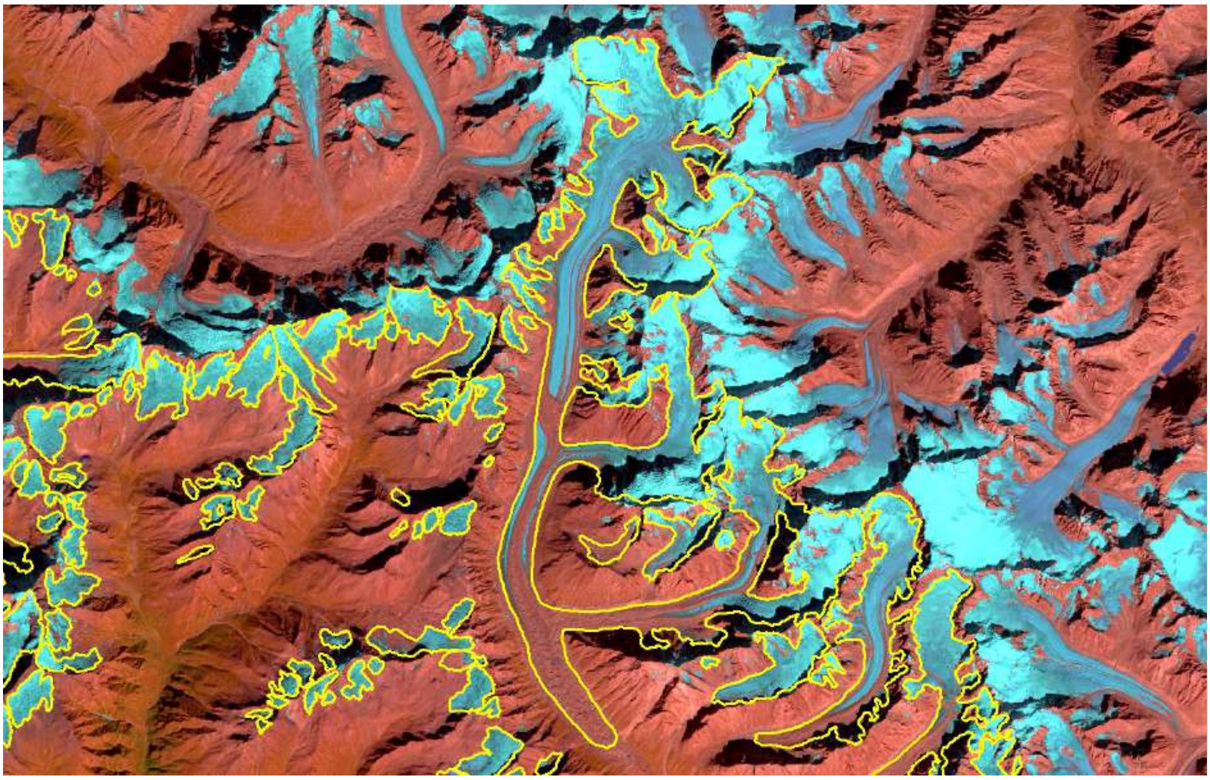


Figure 23 Miyar Glacier, Chenab Basin

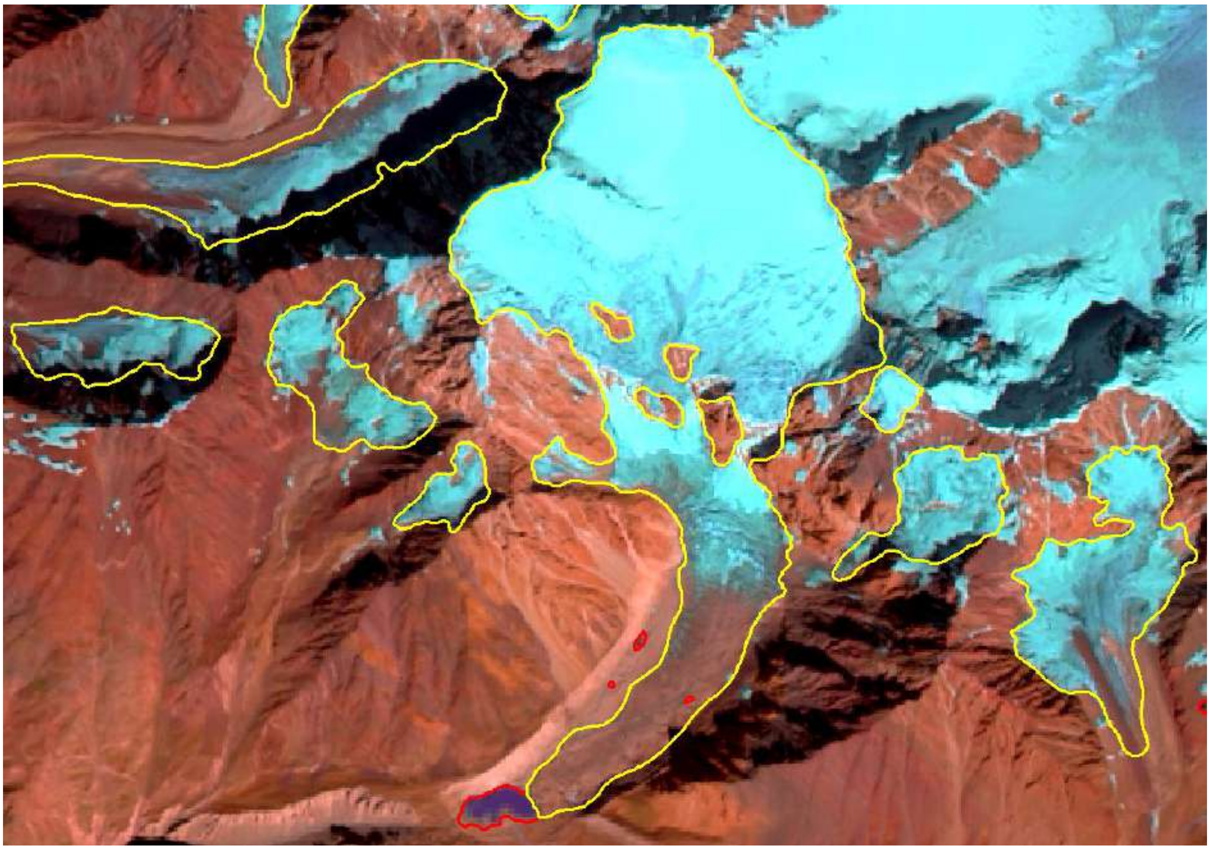


Figure 24 Bhaga Glacier, Chenab Basin

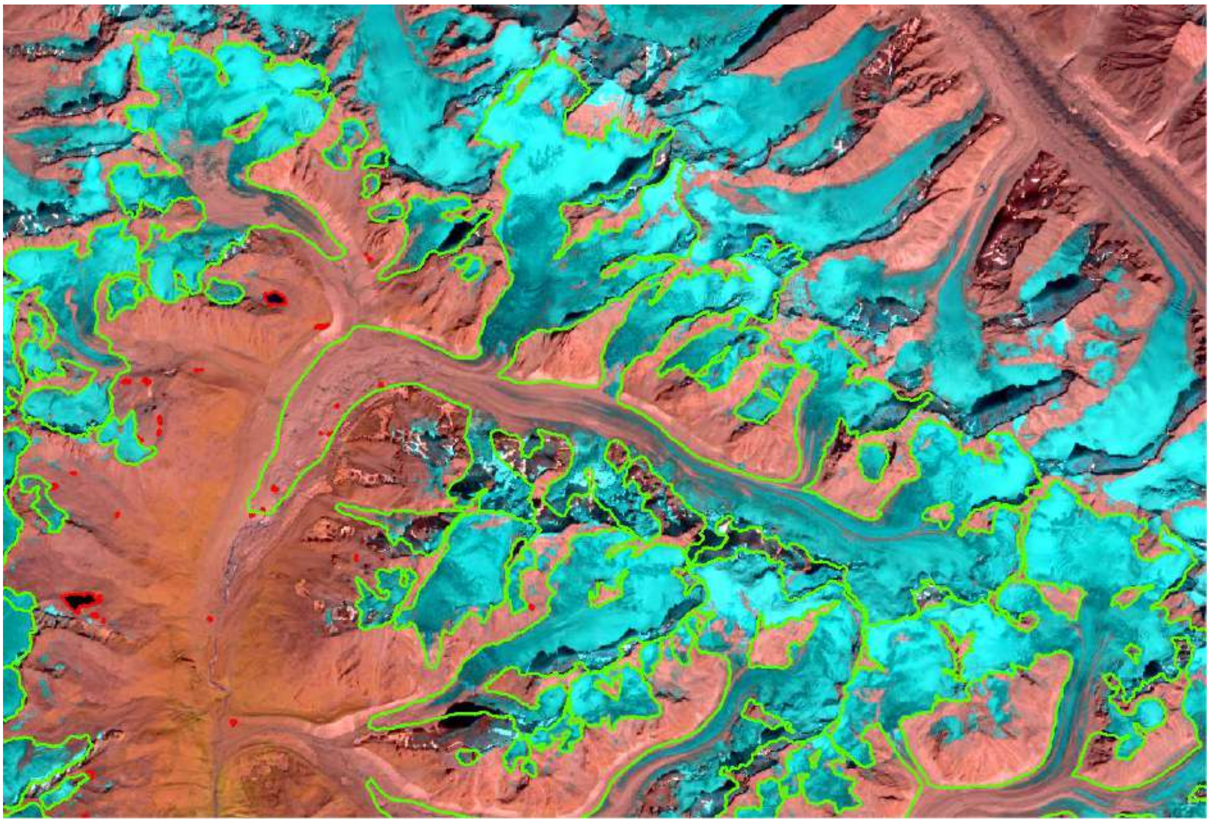


Figure 25 Glaciers of Parwati Sub Basin, Beas Basin

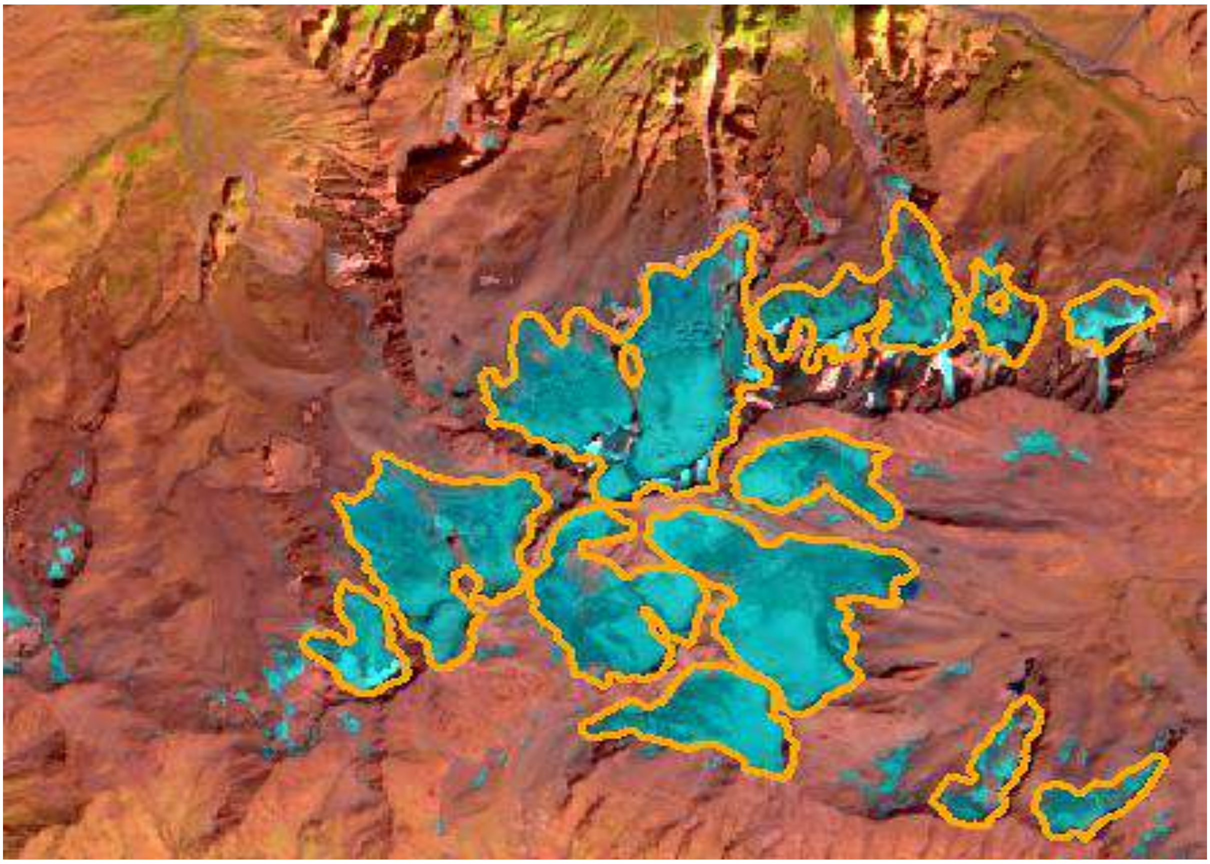


Figure 26 Glaciers of Jiwa Sub Basin, Beas Basin

3. COMPREHENSIVE STUDY AND IMPACT OF CLIMATE CHANGE IN WATER FLOW PATTERN AFFECTING GENERATION OF HYDRO PROJECTS

The comprehensive study and impact of climate change in water flow pattern affecting generation of hydro projects is a Joint study with IISc Bangalore. The satellite data was browsed and procured from Earth explorer and NRSC Hyderabad.

OBJECTIVES

1. Inventory of all glaciers in Satluj catchment right from its origin in the Tibetan Himalayan region from 1980 onwards on a decadal basis using different sets of satellite data.
2. Seasonal Snow cover assessment in the Satluj catchment from 2004 onwards.
3. Collection of runoff data from 1990 onwards.
4. Collection of precipitation and temperature data from 1990 onwards.
5. Mass Balance estimation of glaciers of Satluj river basin.
6. Reconnaissance survey in March/April in Satluj river basin.

Table 11 Inventory of satellite data

S. No.	Activity	Year	Path	Row
1.	Browsed and procured archive satellite data and other data required for inventory	Landsat- MSS		
		31-10-1977	159	38
		15-8-1980	157	38
		29-8-1980	158	37
		14-9-1980	156-	39
		16-9-1980	158	38
		3-10-1980	157	38
		17-10-1981	158	38
		Landsat- TM		
		9-10-1989	147	37
		9-10-1989	147	38
		18-10-1989	146	37
		21-10-1992	143	39
		21-10-1990	146	38
		23-10-1990	144	38
		23-10-1990	144	39
		12-11-1989	145	38
		15-11-1990	145	39
		Landsat ETM		
		8-10-2000	146	38
		13-10-2001	144	39
		15-10-2000	147	37
		15-10-2000	147	38
		2-11-2000	145	38
		Landsat 7(2010)- ETM		
		15-9-2009	146	37
		15-9-2009	146	38
		17-9-2009	144	38
		17-9-2009	144	39
		24-9-2009	145	38
		26-9-2009	143	39
		24-10-2009	147	38
		29-10-2010	145	38
		29-10-2010	145	39
		27-9-2010	145	38
		27-9-2010	145	39
		25-9-2010	147	38
		Landsat 7(2017)- ETM		

		22-10-2017	147	38
		24-10-2017	145	39
		24-10-2017	145	38
		31-10-2017	146	37
		Landsat 8 (2018)- ETM$^+$		
		27-9-2018	143	39
		18-9-2018	144	39
		16-9-2018	146	37
		18-9-2018	144	38
		16-9-2018	146	38
		25-9-2018	145	38
		25-9-2018	145	39
		16-9-2018	146	39
		25-10-2018	147	38
		27-10-2018	145	38
		Landsat 8 (2021)- ETM$^+$		
		7-8-2021	146	37
		16-8-2021	145	38
		16-8-2021	145	39
		18-8-2021	143	39
		23-8-2021	146	38
		30-8-2021	147	38
		26-9-2021	144	39
		15-9-2021	147	38
		1-10-2021	147	38
		3-10-2021	145	38
		3-10-2021	145	39
		10-10-2021	146	37
		10-10-2021	146	38
		12-10-2021	144	38
		12-10-2021	144	39
		IRS-RS2-P6- LISS III		
		1 -08- 2001	96	48
		18 -082007	96	48
		1-09-2018	96	48

4. MONITORING OF PARECHHU LAKE

Parechhu Lake is a small geomorphic depression along the Parechhu River that joins the Spiti River on its left bank near Sumdo in Spiti Sub Division of District Lahaul & Spiti. The fragile geology of the area and the Sumdo Kaurik fault passing nearby cause's activation of the landslides which results in chocking of the river course in the downstream and causes accumulation of the water in the depression. This lake has been known for its damage history and since 2001 is being monitored every year during the ablation season from April to September. During the year 2022, the lake was regularly monitored and its findings about the water spread were reported to the SJVNL as well as to the Government.

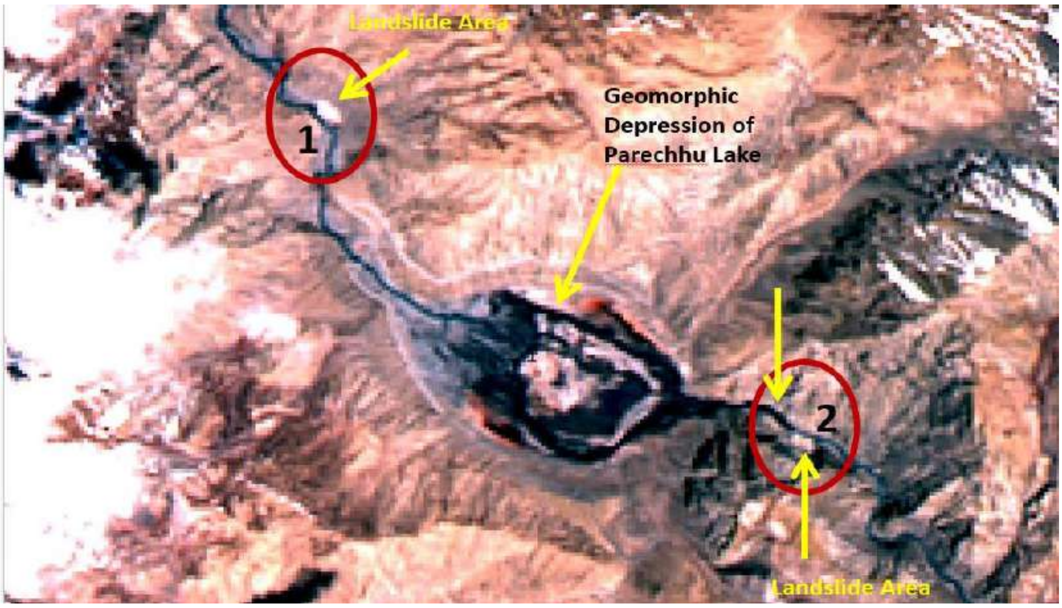


Figure 27 IRS-R2A-LISS III, 96-48, 18 April 2022

Based on the analysis of IRS-R2A-L3-96-48- 18 April, 2022 (Fig 8), satellite data having spatial resolution of 23.5mts, the following observations were made: -

- The accumulated water in the lake depression could be seen through the peripheral sides of the depression and extending downstream upto the point where landslide seems to have caused slight blockade of the river course i.e., about 728.09 mts from the lower point of the lake depression.

- Based on the tonal difference in the river flow, near the landslide 2, the slide seems to have caused a slight blockade in the river course resulting to have the accumulation of the river flow that extends upwards all along the peripheral side in the frontal portion of the lake depression.

- The river flow near the landslide 1 also seems to have some effect on the river flow as a result of which the accumulated water could be seen backwards.

- Besides this, the accumulation could also be seen in the central part of the depression indicating shallow accumulation on the upstream side of the depression, whereas the braiding channels reflecting thick accumulation could be seen on the downstream side along the periphery.

- Although the inflow and the outflow seem to be normal but slight changes like thick accumulation up to the landslide 2 and slightly reduced inflow due to the landslide 1 could be seen.

- Thus, as on day these two landslides may affect the water spread in Parechhu lake i.e., one on the upstream side and the other on downstream of depression and thus needs to be monitored regularly in the coming months in view of the melting of the snow cover from the higher catchments.

- As such based on the satellite data interpretation for the month for April 2022, there does not seem to be any threat from the Parechhu Lake as on day, but needs regular monitoring as it is the beginning of the ablation season and also needs the landslide monitoring in order to assess any further changes in the river flow/ blockade etc. Similarly, the observations were made for the Figure 28, 29 and 30, different satellite imageries for the month of May and June, 2022.

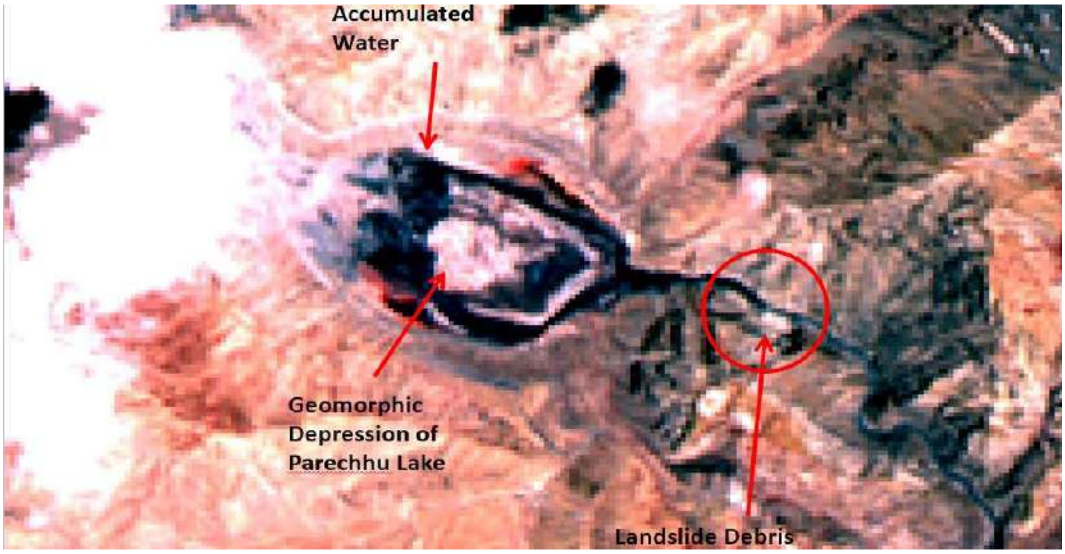


Figure 28 IRS-R2A-LISS III, 96-48, 12 May, 2022

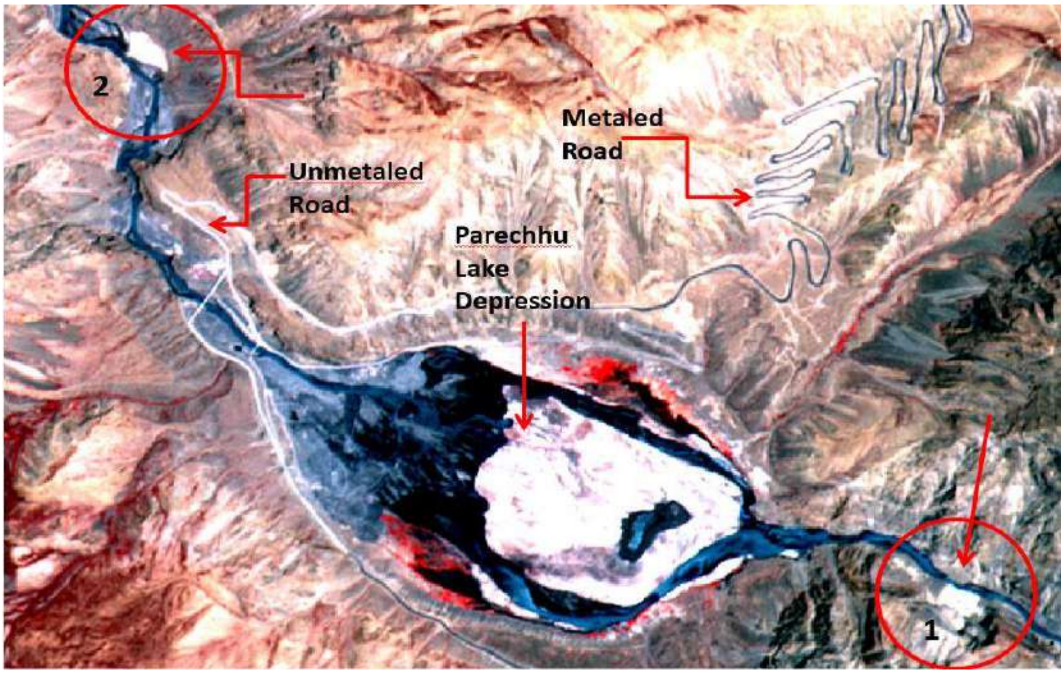


Figure 29 IRS-R2A-LISS IV, 96-48B, 5 June 2022

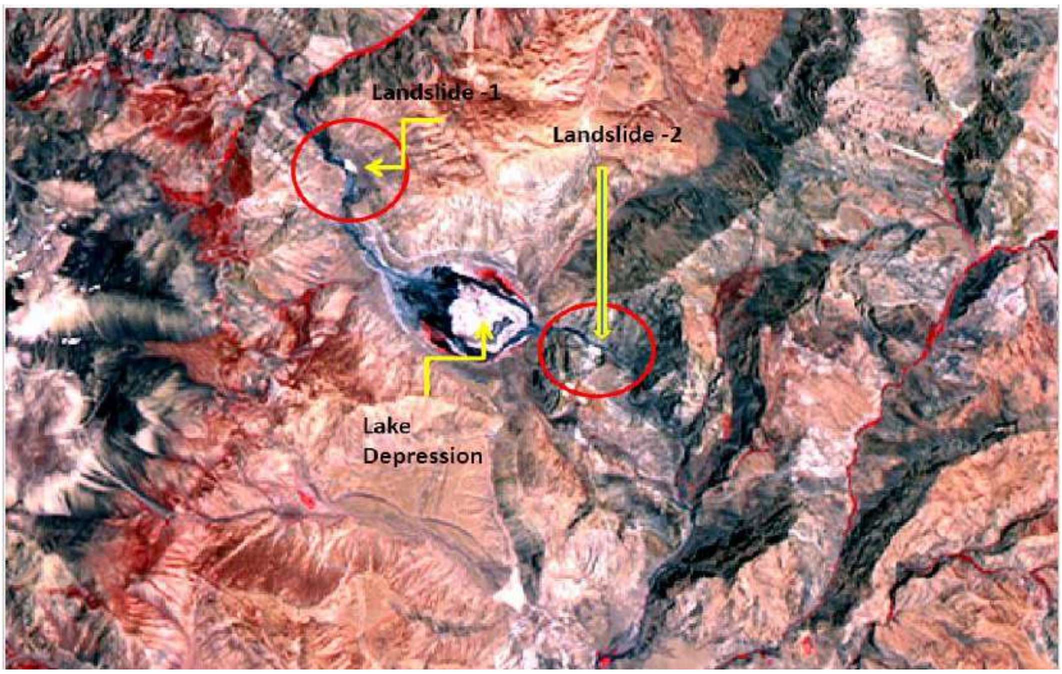


Figure 30 IRS-R2A-LISS III, 96-48, 29 June, 2022

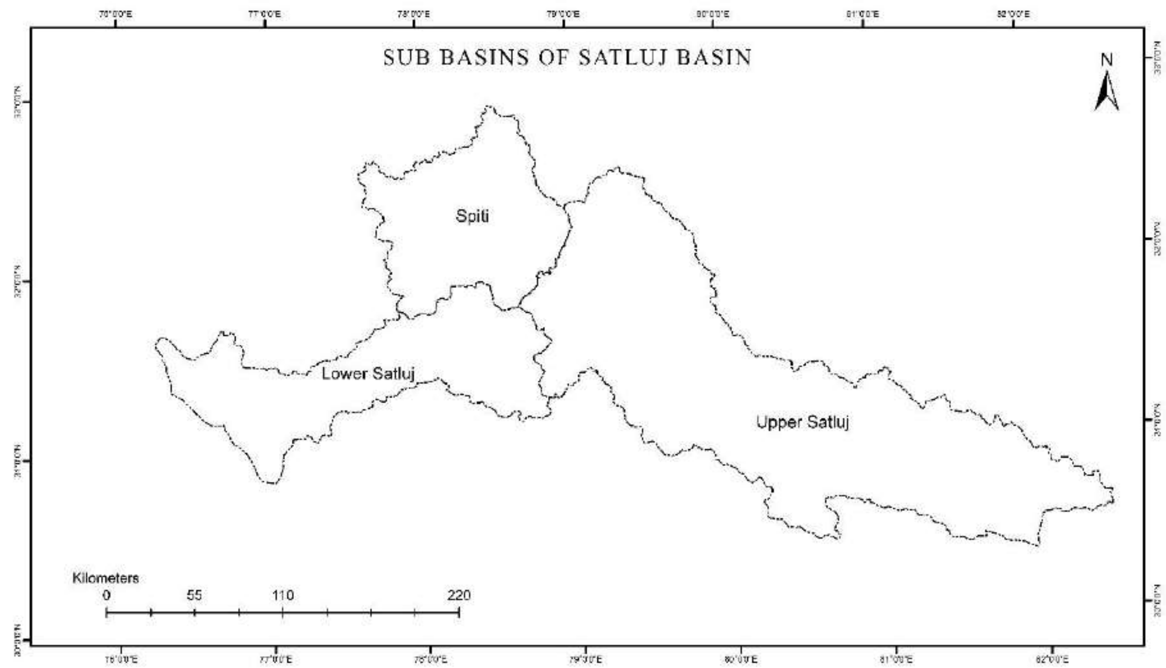
5. MONITORING OF GLACIAL LAKES AND OTHER WATER BODIES USING AWIFS, LISS III AND LISS IV SATELLITE DATA IN SATLUJ CATCHMENT DURING 2022

OBJECTIVES

The main objective of the study is to monitor the water spread area of the all the moraine dammed glacier lakes/ water bodies on monthly basis in the entire Satluj Basin during April to November 2022 based on the inventory of the lakes during the preceding year prepared using space data.

The present study Monitoring of Glacial Lakes in Satluj Catchment has been carried out using IRS–RS2, AWIFS, IRS RS2 & RS2A LISS-III and IRS RS2A LISS -IV and Sentinel Satellite data products having spatial resolution of 56mts, 23.5mts and 5.8mts and 10mts for the year 2022 from April November. The catchment area in the Satluj River basin was studied from upstream of Jhakri to Mansarovar Lake in the Tibetan Himalayan Region from where the Satluj River originates. The study was carried as part of the disaster preparedness plan of Satluj Jal Vidyut Nigam Ltd (SJVNL) to assess the threat from the moraine dammed glacial lakes/water during the year 2022. This study is being carried out regularly since 2009 during the ablation season (April to October/November) every year. During this year, the catchment area was studied during the ablation period from April to November using visual interpretation techniques and an inventory based on AWIFS, LISS III and LISS IV satellite data products was prepared in the Satluj River catchment and thereby assessing any change in their water spread area w.r.t the previous year. In the present study, analysis has been carried out in the study area by using 25 AWIFS data products from April to November and LISS III coverage within the path row 96-48, 96-49, 97-48, 97-49, 98-48, 98-49, 99-49, 100-49 using IRSRS2/RS2A LISS-III data products and 96-48a, 96-48c,96-49b, 97-48a, 97-48c, 98-48a, 98-48c, 100-49c using LISS IV data products. The data gap for LISS IV was tried to fill up with Sentinel data for 2022.

The temporal analysis of the two dates reveals that the Spiti basin shows decrease of 09 lakes in 2022 w.r.t 2021 i.e., 58 (2022) from 67 (2021) and comprising 39 lakes with area less 5ha, 12 lakes with area between 5-10ha and 7 lakes with more than 10ha, or in other words we can say that a reduction of (13%) could be seen in the Spiti basin as a whole between 2021 and 2022. Likewise in Lower Satluj basin, an increase of about 34% w.r.t 2021 is observed i.e., the number of lakes varies from 39 (2021) to 59(2022) comprising 38 lakes having area less than 5ha, 15 lakes within the areal range of 5-10ha and 6 lakes having area more than 10ha. In Upper Satluj basin, a decrease of about 4% w.r.t 2021 could be seen in the total number of lakes mapped as the number varies from 308 (2021) to 297 (2022) comprising 172 lakes with area <5ha, 62 lakes with area between 5-10ha and 63 lakes with area >10ha. Further comparative analysis of the bigger lakes with area >10ha reflects that 17% enhancement could be seen in total number of lakes w.r.t 2021 and total number of lakes falling in this category varies 31(2019) to 62 (2020) to 66(2021) to 76 (2022) out of which 12 are the high-altitude wetlands forming part of the Upper Satluj basin.



AWiFS Satellite data used for monitoring in the study area			
Sr. No.	**Date of Pass**	**Path –Row**	**Satellite Sensor**
1	01 April 2022	95-49	Resourcesat2/AWIFS
2	11 April 2022	97-49	Resourcesat2/AWIFS
3	05 May 2022	97-50	Resourcesat2A/AWIFS
4	19 May 2022	95-48	Resourcesat2/AWIFS
5	03 June 2022	98-47	Resourcesat2/AWIFS
6	13 June 2022	100-49	Resourcesat2/AWIFS
7	02 July 2022	97-47	Resourcesat2A/AWIFS
8	04 July 2022	97-47	Resourcesat2A/AWIFS
9	31 Aug 2022	99-48	Resourcesat2A/AWIFS
10	31 Aug 2022	99-48	Resourcesat2A/AWIFS
11	07 Sep 2022	98-49	Resourcesat2/AWIFS
12	07 Sep 2022	98-49	Resourcesat2/AWIFS
13	11 Sep 2022	94-49	Resourcesat2A/AWIFS
14	12 Sep 2022	99-49	Resourcesat2A/AWIFS
15	26 Sep 2022	97-49	Resourcesat2A/AWIFS
16	06 Oct 2022	99-48	Resourcesat2A/AWIFS
17	15 Oct 2022	96-49	Resourcesat2A/AWIFS
18	25 Oct 2022	98-49	Resourcesat2/AWIFS
19	27 Oct 2022	96-48	Resourcesat2/AWIFS
20	27 Oct 2022	96-48	Resourcesat2/AWIFS
21	30 Oct 2022	99-49	Resourcesat2/AWIFS
22	03 Nov 2022	95-49	Resourcesat2/AWIFS
23	13 Nov 2022	97-49	Resourcesat2/AWIFS
24	22 Nov 2022	94-49	Resourcesat2/AWIFS
25	23 Nov 2022	98-49	Resourcesat2/AWIFS
LISS-III Satellite data used for monitoring in the study area			
Sr. No.	**Date of Pass**	**Path –Row**	**Satellite Sensor**
1	28 Aug 2022	96-48	Resourcesat2/LISS III
2	28 Aug 2022	96-49	Resourcesat2/LISS III
3	31 Aug 2022	99-48	Resourcesat2A/LISS III
4	31 Aug 2022	99-49	Resourcesat2A/LISS III
5	02 Sep 2022	97-48	Resourcesat2/LISS III
6	05 Sep 2022	100-49	Resourcesat2A/LISS III
7	12 Sep 2022	99-48	Resourcesat2/LISS III

8	12 Sep 2022	99-49	Resourcesat2/LISS III
9	16 Sep 2022	95-47	Resourcesat2/LISS III
10	29 Sep 2022	100-49	Resourcesat2A/LISS III
11	05 Oct 2022	94-48	Resourcesat2/LISS III
12	15 Oct 2022	96-48	Resourcesat2A/LISS III
13	17 Oct 2022	94-48	Resourcesat2A/LISS III
14	08 Nov 2022	96-48	Resourcesat2/LISS III
LANDSAT-8 Satellite data used for monitoring in the study area			
Sr. No.	**Date of Pass**	**Path –Row**	**Satellite Sensor**
1	26 Aug 2022	146-38	OLI+
2	27 Aug 2022	145-38	OLI+
3	12 Sep 2022	145-38	OLI+
4	29 Sep 2022	144-38	OLI+
5	29 Sep 2022	144-39	OLI+
6	22 Oct 2022	145-39	OLI+
LISS-IV Satellite data used for monitoring in the study area			
Sr. No	**Date of Pass**	**Path –Row**	**Satellite Sensor**
1	28 Aug 2022	96-48A	Resourcesat2/LISS IV
2	28 Aug 2022	96-48C	Resourcesat2/LISS IV
3	02 Sep 2022	97-48A	Resourcesat2/LISS IV
4	07 Sep 2022	98-49A	Resourcesat2/LISS IV
5	07 Sep 2022	98-48C	Resourcesat2/LISS IV
6	07 Sep 2022	98-49C	Resourcesat2/LISS IV
7	26 Sep 2022	97-49B	Resourcesat2/LISS IV
8	29 Sep 2022	100-49C	Resourcesat2A/LISS IV
9	03 Oct 2022	96-48C	Resourcesat2/LISS IV
10	15 Oct 2022	96-48A	Resourcesat2/LISS IV
11	15 Oct 2022	96-48C	Resourcesat2/LISS IV
12	20 Oct 2022	97-48C	Resourcesat2/LISS IV
13	01 Aug to 31 October,2022	Sentinel data	Google Earth engine

Further it is found that the in Spiti basin, the number of lakes with area >10ha varies from 1 **(**2019) to 7 (2020) to 7(2021) to 7(2022), in Lower Satluj basin the number of such lakes varies from 0 (2019) to 2 (2020) to 6(2021), 6(2022) whereas in Upper Satluj basin the number of such lakes varies from 30 (2019) to 53 (2020) to 53 (2021) to 63 (2022). Although the number of total lakes in 2021 and 2022 remains the same i.e. 414, but the lakes with area more than 10 ha has increased from 66 (2021) to 76 (2022) which is mainly due to the fact that 13 lakes with ids (71, 312, 423, 611, 658, 827, 1053, 1531, 8280, 8288, 8517, 211 HWL, 616 RS) which were in the aerial range of 5-10 ha during 2021 have shown an increase in their area during 2022 and have been counted in the next higher category i.e. more than 10ha. On comparing the total lakes in 2022 with that of base line data of 2007(196) a gradual increasing trend could be seen from 2012 onwards and the number varies from 128(2012) to 130)2013) to 192(2014) to 241(2015) to 280(2016) to 280(2017) to 273(2018) to 229(2019) to 361(2020) to 414(2021) and 414(2022) reflecting an enhancement of about 223% in terms of the total number of lakes which includes lakes from the glacial origin as well as the high altitude wetlands with reference to the base line data of 2012(128) and about 111% w.r.t that of 2007(196).

Based on the updated inventory of glacial lakes using LISS III satellite data during 2022, total number of lakes /wetlands mapped varies from 769 (2018) to 562 (2019) to 993 (2020) to 880 (2021) to 995 (2022). Out of these total 995 lakes mapped in 2022, 850 lakes have been mapped as the small one with area less 5ha, 83 lakes with area 5-10 ha and 62 lakes with area more than 10ha. Further, out of 995 lakes mapped, 71 are mainly the high-altitude wetlands based on their source of origin. The comparative analysis based on LISS-III satellite data from 2018-2022 reveals an overall reduction of about 26% between 2018 -19 and further an enhancement by about 76% between 2019-20 and about 11% reduction between 2020-21 and again 13% enhancement between 2021-22 respectively. In terms of the bigger lakes/wetlands, the number varies from 49 (2018) to 51 (2019) to 62(2020) to 56(2021) and 62 (2022). Basin wise distribution of lakes based on LISS III reflects that in Upper Satluj basin, the number of lakes varies from 495 (2018) to 437 (2019) to 707 (2020) to 588 (2021) to 639 (2022) , in Lower Satluj basin the number varies from 98 (2018) to 52 (2019) to 89 (2020) to 163(2021) to 173(2022) and in case of Spiti sub basin it varies from 176 (2018) to 73 (2019) to 197 (2020) to 129(2021)to 183(2022) reflecting an enhancement by about 9% (2021-22) in case of Upper Satluj basin, 6% (2021-22) in case of Lower Satluj and an enhancement by about 41% (2021-22) in case of Spiti basin. Further in Spiti basin , the lakes with ids 1682RS (2.05ha), 1683RS (11.82ha), 1684RS (3.81ha), 1685RS(2.37ha), 1686RS (0.43ha), 1687RS (1.19ha), 9003RS (1.59ha), 9004RS(0.55ha), in Lower Satluj basin lakes with ids 9207RS (4.55ha), 9058RS (0.41ha), and in Upper Satluj basin , the lakes with ids 1557RS (71.15ha), 1771RS (13.73ha), 1772RS (4.89ha), 1775RS (5.57ha) 2170RS (2.32ha) and 10326RS (13.47) are some of the water bodies which have been developed along the nala sections in the different sub basins and needs monitoring as they are the potential locations for causing flash floods downstream.

Further analysis of very high-resolution satellite data of LISS IV, a total of 1953 lakes/high altitude wetlands have been mapped in the Satluj catchment in comparison to 1632 (2021) and 1359(2020). Basin wise distribution of 1953 lakes /wetlands reveals that 368 (19%) lakes are from Spiti basin, 250 (13%) from the Lower Satluj basin and 1335 (68%) from the Upper Satluj basin i.e., basin 3, out of which 37 lakes have been classified as high-altitude wetlands and the remaining 1916 as from the glacial origin. Further out of 1953 lakes/wetlands delineated, 1849 were the small one with area less than 5ha, 56 were within the area range of 5-10 ha and 48 were the one which have the area more than 10ha respectively in other words we can say that (94%) were the small one with area less than 5ha, (3%) were within the areal range of 5-10ha and (about 3%) were the big one with area more than 10ha. Based on the analysis carried out using three different sets of satellite data i.e., AWIFS, LISS III and LISS IV, it is observed that in Spiti basin, the number of lakes delineated has been enhanced from 58 with AWIFS sensor to 183 with LISS III sensor and further 368 with LISS IV sensor in 2022 in comparison to 67 with AWIFS to 129 with LISS III to 379 with LISS IV in 2021. Likewise, in Lower Satluj basin, the 59 lakes delineated from AWIFS sensor increased to 173 in LISS III and 250 with LISS IV sensor in 2022 in comparison to 39, 163 and 529 with AWIFS, LISS III and LISS IV sensors in 2021. Similarly, in Upper Satluj basin, the 297 lakes as delineated from AWiFS sensor has increased to 639 with LISS III and 1335 with LISS IV in 2022 in comparison to 308 with AWIFS, 588 with LISS III and 724 with LISS IV in 2021 respectively and the variation is mainly due to the data gap in LISS IV which mainly covers the areas falling in Spiti & Upper Satluj basins. Thus, from the above analysis based on different sensors, it is inferred that the level of information has increased depending upon the sensor being used in the investigation i.e., LISS IV sensor provides the better information in comparison to AWIFS and LISS III about the catchment. The percentage increase with different sensors varies from 20% (2021-22) with LISS IV and 13% (2021-22) with LISS III, whereas no increase could be observed with AWIFS data in case of total number of lakes but the lakes with area more than 10 ha has increased during 2021-22.

The Parechhu Lake is another potential vulnerable lake in the Satluj catchment that was formed in 2004 in the Trans Himalayan Region of the Tibetan Plateau by virtue of damming of the river course due to landslide. Since this lake is very much close to the Sumdo-Korik fault, which is prominent Geological Structure that may have activated resulting to landslides in the region. The lake was formed because of the landslide from the left bank in 2004 and since then this is being monitored regularly using space data. During 2022, the lake was monitored and does not show any major change in its water spread and seems to be stable based on the observations made which have been reported to SJVNL as well as to the Government during 2022 during June, July & October. But the presence of landslide on the upstream side of the lake depression and another one on the right bank is a likely threat for its damming again and thus needs to be monitored in order to assess any change in the water level by virtue of the landside which may block the river course causing major threat like that of the Parechhu formation during the year 2004.

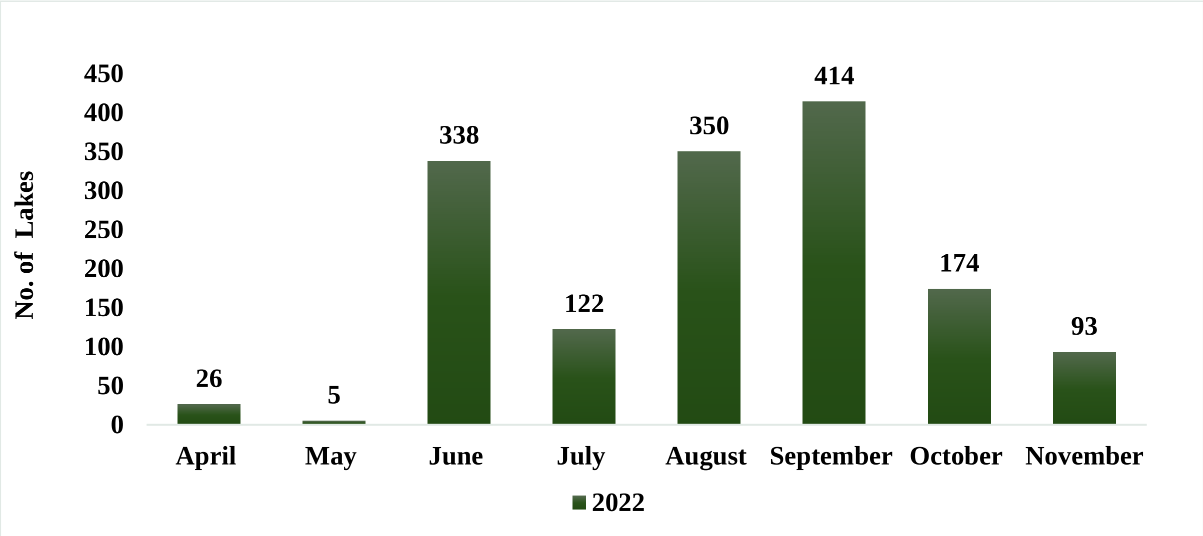


Figure 31 Total No. of Lakes based on AWiFS satellite data, 2022

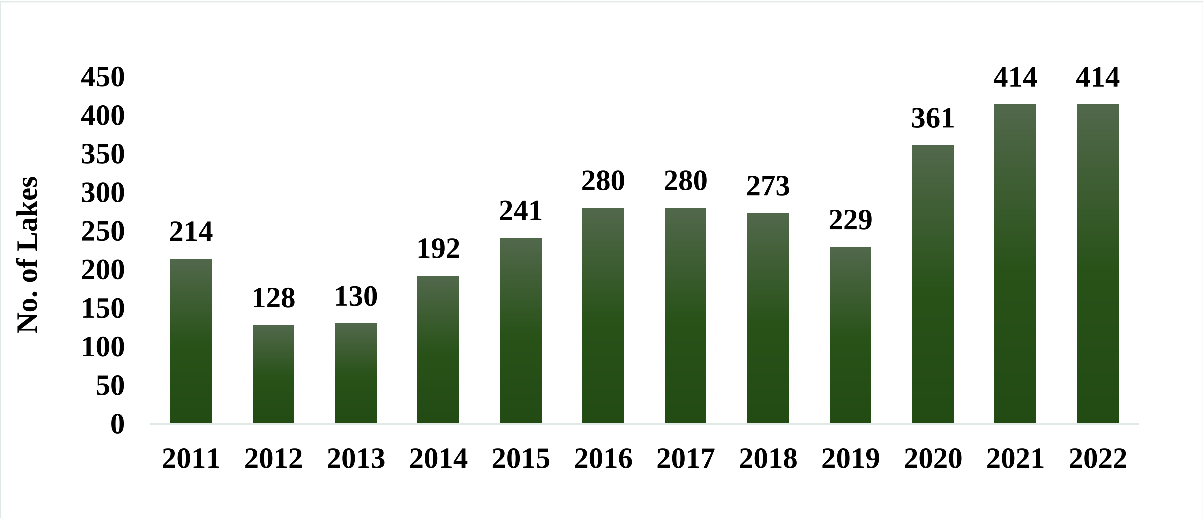


Figure 32 Total number of Lakes based on AWiFS Data (2011-2022)

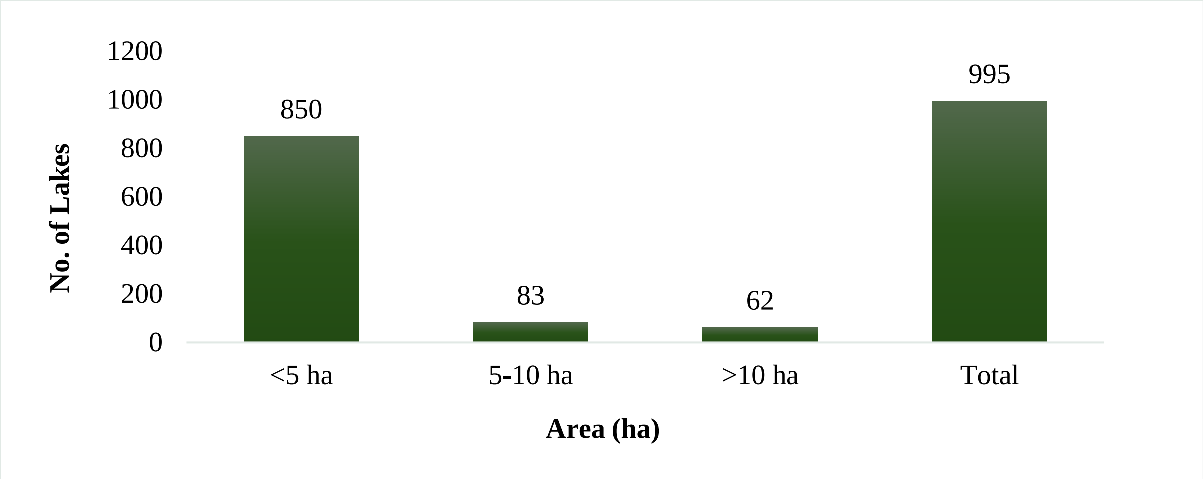


Figure 33 Total no. of Lakes in Satluj Basin based on LISS III Satellite Data (2022)

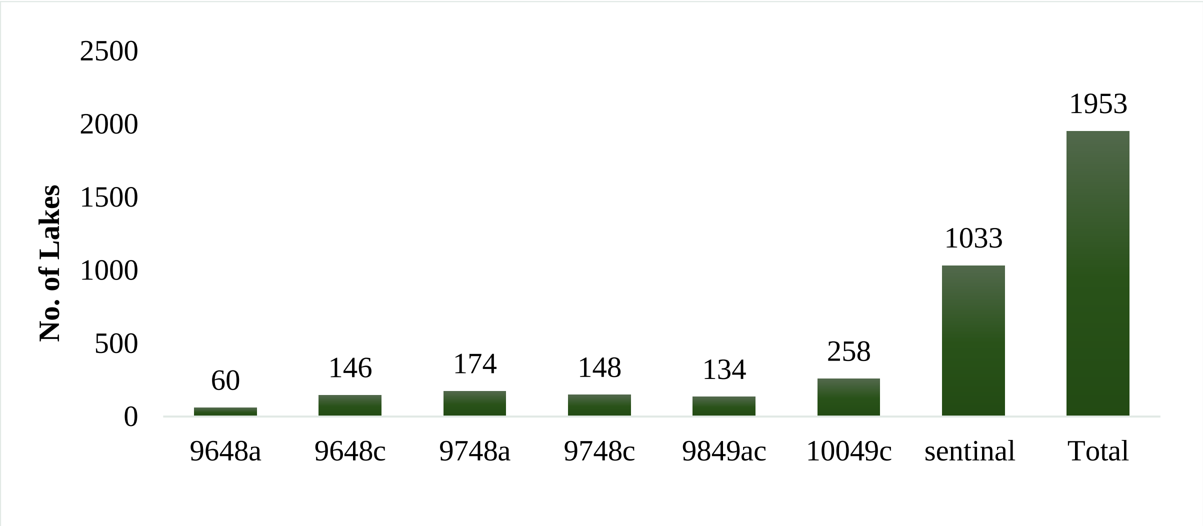


Figure 34 Total no. of Lakes in Satluj Basin based on LISS III Satellite Data (2022)

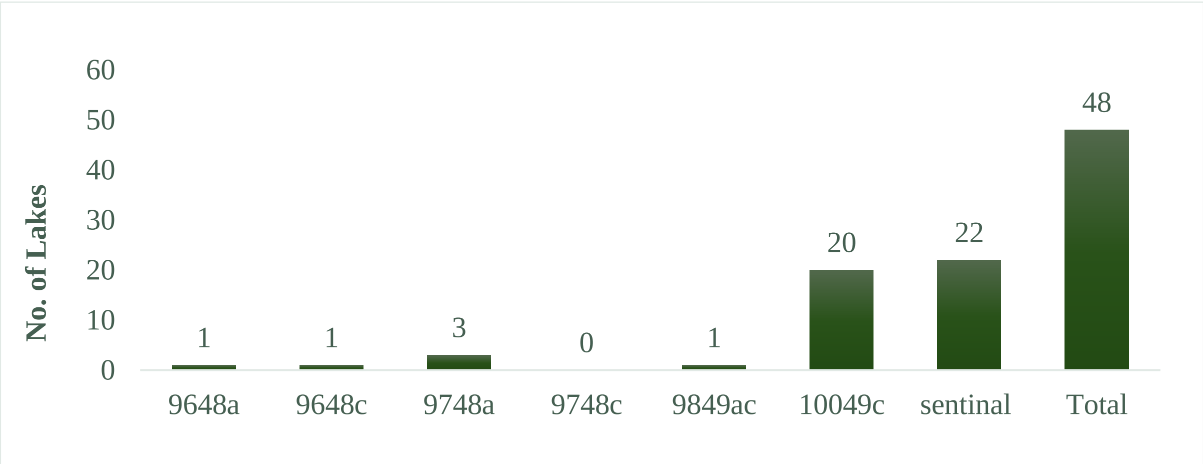


Figure 35 No. of Lakes > 10 ha LISS IV and Sentinel Data 2022

Table 12 Comparative analysis of three different sensors

Sr. no	Basin Name	AWiFS (56mts)			LISS -III (23.5mts)			LISS-IV (5.8mts)		
		2020	**2021**	**2022**	**2020**	**2021**	**2022**	**2020**	**2021**	**2022**
1	Spiti Basin (1)	62	67	55	197	129	183	225	379	368
2	Lower Satluj (2)	20	39	62	89	163	173	542	529	250
3	Upper Satluj (3)	279	308	297	707	588	639	592	724	1335
4	**Total Satluj Basin**	**361**	**414**	**414**	**993**	**880**	**995**	**1359**	**1632**	**1953**

CONCLUDING REMARKS

To summarize that based on the observations made from the analysis of AWIFS, LISS III and LISS IV data products in the catchment area of Satluj Jal Vidyut Nigam Ltd. from upstream of Jhakari up to the Mansarover lake in the Tibetan region, it is concluded that the frequency of lake formations varies in each basin, which is evident from the different comparative analysis in all the three sub basins of the Satluj catchment. From the basin wise analysis, it is inferred that number of lakes delineated is much higher in the Tibetan Himalayan Region i.e., Upper Satluj basin in comparison to the other two basins i.e., Spiti and Lower Satluj basins, which signifies that Upper Satluj basin is more susceptible for the glacial lake formations and the permafrost leading to more lake formations i.e., the high-altitude wetlands. This may be due to the fact that the temperatures over the high mountain regions are reported to be comparatively higher than the low-lying areas which adversely affects the Himalayan glaciers thereby increasing the formation of moraine dammed glacial lakes in front of the glacier snouts at the higher reaches. Considering the geographical locations of these lakes, the space data has been proved to be very useful and has a great potential in monitoring such developments on the higher reaches as it would not be possible by any other conventional methods. Thus, using space data, the variation in the spatial extent of different category of lakes can be estimated, which would help in assessing their vulnerability if any arising out of the increasing water spread considering the Guidelines on Management of Glacial Lake Outburst Floods (GLOFs), Landslide Lake Outburst Floods (LLOFs) of NDMA (MHA)-2020 of Govt. of India which suggest that detailed inventory of such lakes is required to be carried out on regular basis and with detailed analysis for the potential locations which includes field analysis as well. The recent tragedy of 2013 in the Uttarakhand Himalaya has also been correlated with the bursting of a lake having a total area of about 08 hectare in front of the snout of the Chorabari glacier that caused widespread damage in the downstream areas besides the heavy rainfall (Dobhal et.al.2013) and the recent tragedy of 2021 which was reported to be because of the ice avalanche resulting to temporary damming in the river course and causing flash floods downstream. Thus, the magnitude of such lakes as far as the destruction is concerned cannot be overruled. Hence the lakes with area >10 hectare and the area between 5-10 hectare can be seen as the potential vulnerable sites considering the present trends in the climate science and the climate induced hazards threat thereof, for causing damage in case of bursting of any one of them by virtue of avalanche or any tectonic activity considering the high seismicity of the Himalayan region. Thus, a proper monitoring of all such lakes using high resolution space data is essential, which is not possible by any other conventional methods in order to avoid any eventuality like that of the Parechhu and other instances of GLOFs (Glacier Lake Outbursts Floods) in the Himalayan Region of Nepal and Bhutan and the recent incidents that had happened in Uttarakhand Himalaya, which will not only save the precious human lives but also the public and the Govt. property.

6. MAPPING OF MULTI HAZARDS

OBJECTIVES

To generate geodatabase of Multi Hazards maps such as flood plains, landslides, GLOFs etc. by using high resolution satellite data LISS IV (spatial resolution: 5.8mtrs).

FLOOD PLAINS/ LOW LYING AREAS

Naturally water flows from the high areas towards low lying areas. This means low-lying areas may flood quickly before it begins to get to the higher ground. Whenever there are more rains taking place than the drainage system can take, they can result in floods.

PRELIMINARY INTERPRETATION OF FLOOD PLAINS OR LOW-LYING AREAS OF DISTRICT UNA, HAMIRPUR AND BILASPUR

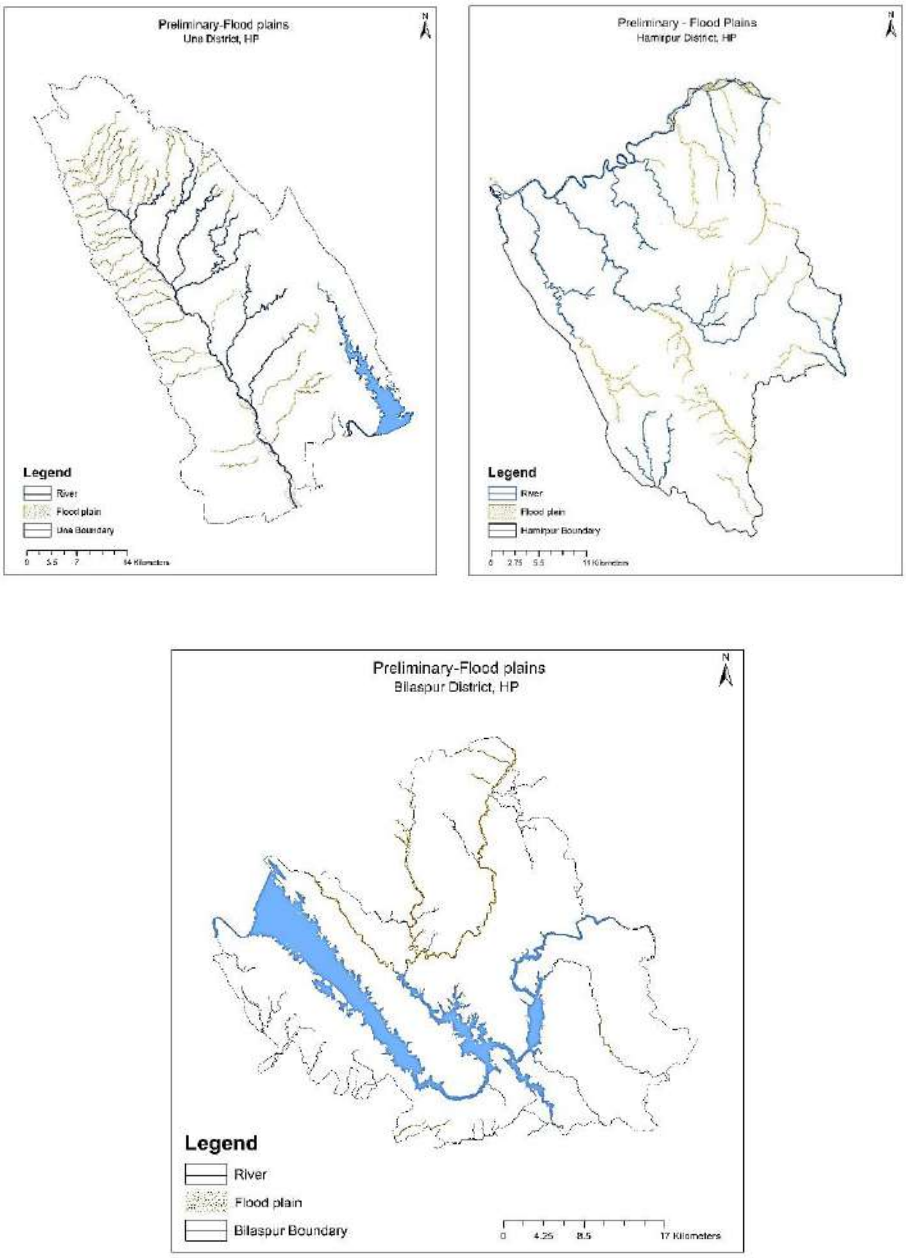


Figure 36 Maps of Preliminary-Food plains of Una, Hamirpur & Bilaspur district, Himachal Pradesh

WETLANDS OF HIMACHAL PRADESH 2018-19

Wetland of Himachal Pradesh for the 2018-19 (LISS IV Satellite data)

OBJECTIVES

1. Create layer of Wet boundary of Himachal Pradesh using Pre monsoon LISS IV satellite images at Scale of 1:25,000
2. Create layer of Wetprbnd18 using Pre monsoon LISS IV satellite images of Himachal Pradesh at Scale of 1:25,000 with Wetcode and Wetcode
3. Create layer of Wetpobnd18 Using Post monsoon LISS IV satellite images of Himachal Pradesh at Scale of 1:25,000 with Wetcode and Wetcode
4. Create layer of aqvegpr18 using Pre monsoon LISS IV satellite images of Himachal Pradesh at Scale of 1:25,000
5. Create layer of aqvegpo18 using Pre monsoon LISS IV satellite images of Himachal Pradesh at Scale of 1:25,000
6. Create layer of road18 using Post monsoon LISS IV satellite images
7. Create layer of settlep18 using Post monsoon LISS IV satellite images

Pre-Monsoon Satellite Imageries			
Sr. No.	Date of Pass	Path/Row	Sensor
1.	07-Mar-2018	94/48	IRS-R2A-L4FX-C
2.	12-Mar-2018	95/48	IRS-R2A-L4FX-D
3.	24-Mar-2018	95/47	IRS-R2-L4FX-C
4.	24-Mar-2018	95/48	IRS-R2-L4FX-A
5.	24-Mar-2018	95/49	IRS-R2-L4FX-A
6.	29-Mar-2018	96/48	IRS-R2-L4FX-A
7.	29-Mar-2018	96/49	IRS-R2-L4FX-A
8.	19-Mar-2018	94/47	IRS-R2-L4FX-C
9.	31-Mar-2018	94/48	IRS-R2A-L4FX-D
10.	17-Mar-2018	96/48	IRS-R2A-L4FX-D
11.	12-Mar-2018	95/47	IRS-R2A-L4FX-D
12.	29-Mar-2018	96/48	IRS-R2-L4FX-C
13.	10-Mar-2018	97/49	IRS-R2-L4FX-A

14.	29-Mar-2018	96/49	IRS-R2-L4FX-C
15.	29-Mar-2018	96/49	IRS-R2-L4FX-A
16.	24-Mar-2018	95/49	IRS-R2-L4FX-A
17.	31-Mar-2018	94/48	IRS-R2A-L4FX-D
18.	24-Mar-2018	95/48	IRS-R2-L4FX-A
19.	19-Mar-2018	94/48	IRS-R2-L4FX-A
20.	24-Mar-2018	95/49	IRS-R2-L4FX-A
21.	31-Mar-2018	94/49	IRS-R2A-L4FX-B
22.	12-Mar-2018	95/49	IRS-R2A-L4FX-D
23.	24-Mar-2018	95/49	IRS-R2-L4FX-C
24.	12-Mar-2018	95/48	IRS-R2A-L4FX-B
25.	20-May-2018	94/47	IRS-R2A-L4FX-D
26.	29-Mar-2018	96/48	IRS-R2-L4FX-C
27.	10-Mar-2018	97/49	IRS-R2-L4FX-A
28.	12-Mar-2018	95/49	IRS-R2A-L4FX-B
29.	30-May-2018	94/48	IRS-R2-L4FX-B
30.	31-May-2018	95/48	IRS-R2-L4FX-C
31.	17-Mar-2018	96/49	IRS-R2A-L4FX-B
Post Monsoon Satellite Imageries			
Sr. No.	Date of Pass	Path/Row	Sensor
1.	05-Nov-2017	096-049	IRS-R2-L4FX-A
2.	21-Oct-2019	94/48	IRS-R2A-L4FX-A
3.	26-Oct-2019	95/48	IRS-R2-L4FX-A
4.	26-Oct-2019	95/49	IRS-R2-L4FX-A
5.	02-Oct-2019	95/49	IRS-R2-L4FX-B
6.	07-Oct-2017	95/48	IRS-R2-L4FX-B
7.	24-Nov-2019	96/49	IRS-R2-L4FX-C
8.	26-Oct-2017	94/47	IRS-R2-L4FX-C
9.	26-Oct-2019	95/47	IRS-R2-L4FX-C
10.	26-Oct-2019	95/49	IRS-R2-L4FX-C
11.	31-Oct-2017	95/48	IRS-R2-L4FX-C

12.	07-Oct-2017	95/47	IRS-R2-L4FX-D
13.	07-Oct-2017	95/48	IRS-R2-L4FX-D
14.	07-Oct-2017	95/49	IRS-R2-L4FX-D
15.	22-Nov-2017	97/48	IRS-R2A-L4FX-A
16.	22-Nov-2017	97/49	IRS-R2A-L4FX-A
17.	30-Sep-2017	96/48	IRS-R2A-L4FX-A
18.	07-Nov-2017	94/48	IRS-R2A-L4FX-B
19.	24-Oct-2017	96/49	IRS-R2A-L4FX-B
20.	28-Oct-2019	94/49	IRS-R2A-L4FX-B
21.	30-Dec-2019	97/48	IRS-R2A-L4FX-C
22.	30-Sep-2017	96/47	IRS-R2A-L4FX-C
23.	30-Sep-2017	96/48	IRS-R2A-L4FX-C
24.	20-Sep-2017	94/47	IRS-R2A-L4FX-D
25.	24-Oct-2017	96/48	IRS-R2A-L4FX-D
26.	24-Oct-2017	96/48	IRS-R2A-L4FX-D
27.	28-Oct-2019	94/48	IRS-R2A-L4FX-D
28.	21-Oct-2019	94/48	IRS-R2A-L4FX-C

RESULTS

Area estimates of various wetland categories have been carried out using GIS layers of wetland extent/boundary of the year 2018-19 by using LISS IV Satellite data having resolution of 5.8 meters. The total 2343 wetland polygons of Inland Wetlands –Natural (Lakes, Ponds, High altitude Wetlands, Waterlogged and River and its tributaries) and Inland Wetlands –Man made (Reservoirs/barrages, tanks/ ponds, Aquaculture Ponds and Canals) have been mapped at 1:25,000 scale in the state. Total estimated wetland area of Himachal region is 118582.86 ha which accounts for about 2.12 % of geographical area of the region. Inland-natural wetlands (75099 ha) accounted for around 63.33 per cent of the total wetland area (98321 ha), while inland man-made wetlands (43483 ha) accounts for 36.66 %. As far as inland natural wetland units are concerned, lakes and ponds occupy about 40 ha which is (0.03 %), high altitude wetland occupy (0.01%), waterlogged area accounts 53.47 ha (0.045%) and river stream occupies 69746.78 ha (51.82%) of total wetland area reflecting that inland natural wetland area (57.9%) is more than the man-made wetlands (36.66%).

S. No.	**Wetland Category**	**2017-18 (LISS IV Resolution 5.8 Metres)**	
		Total Wetland Area (ha)	**% of wetland area**
Sub-total: Inland Wetlands -Natural		75099.45	63.33
1	Lakes/Ponds (1101)	40.25758	0.033949
2	High altitude wetlands (1103)	12.18	0.010271
3	Waterlogged (1105)	53.47039	0.045091
4	River/Stream (1106)	69746.78	58.81692
5	River – Aquatic beds (9999)	5246.769	4.424559
Sub-total: Inland Wetlands - Man-made		43483.41	36.66
5	Reservoirs/Barrages (1201)	43082.45	36.33109
6	Tanks/Ponds (1202)	337.5128	0.284622
7	1205	22.81599	0.019241
8	Canal (1206)	40.63031	0.034263
Total Inland Wetland		**118582.86**	**100**

AGRICULTURE & HORTICULTURE SECTOR

7. IMPACT OF CLIMATE CHANGE IN HORTICULTURE CROPS OF SOLAN DISTRICT, HIMACHAL PRADESH

With noticeable changes in productivity, crop yield quality, and acreage already being observed globally, climate change has become a major problem for the horticulture sector. Seasonal trends in climatic variables such as minimum, maximum, and diurnal temperatures, as well as rainfall patterns (quantity and rainy days), were combined with a standardised anomaly index to determine the relationship between climate and crop production based on the phenological stages of pre-flowering, flowering, and fruit setting. To achieve these goals, 30 years (1990–2019) of horticulture data including production, acreage, and temperature of the Solan district were analysed by using statistical tools such as the Standardized Anomaly Index (SAI), the Menn Kendall Test, and Multivariate Linear Regression Analysis.

CLIMATE TREND AND HORTICULTURE

To study the impact of climate change in the Solan district of Himachal Pradesh, temperature (minimum, maximum, diurnal) and rainfall are used as explanatory indicators to capture the crux of climatic changes in the district.

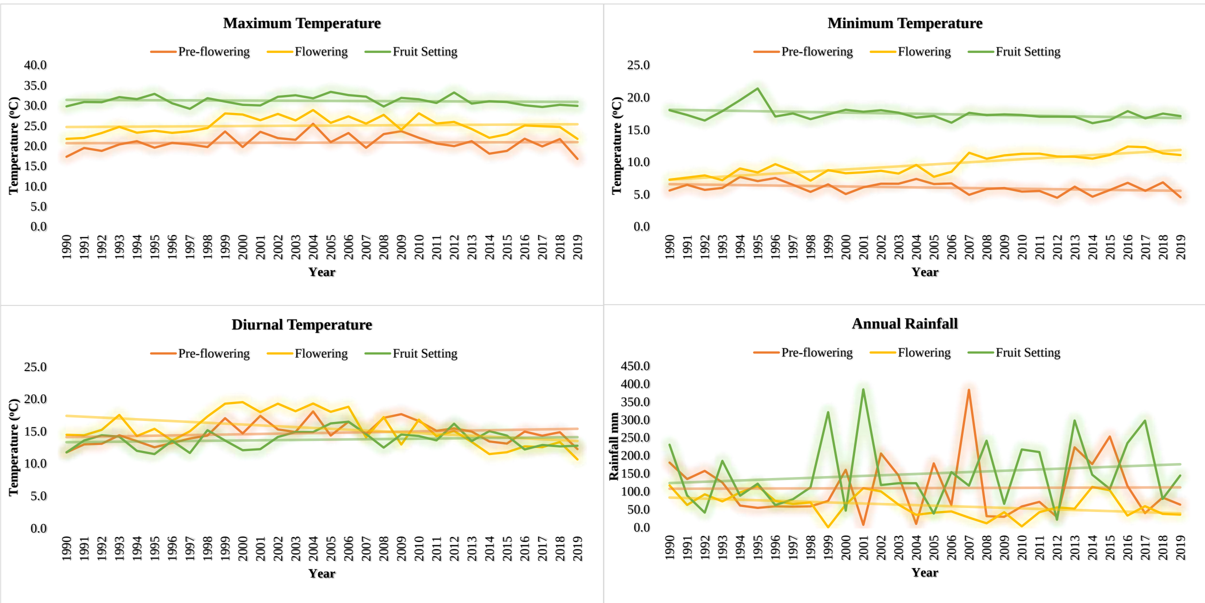


Figure 37 Variations in Climatic Parameters for Temperate region- Minimum T, Maximum T, Diurnal T and Rainfall during pre-flowering, flowering, and fruit setting stages (1990-2019), District Solan, HP

A highly significant shift in climatic factors was noticed during the pre-flowering season, flowering season, and fruit setting season, according to the statistical analysis, Mann-Kendall trend test. The Mann-Kendall test findings for minimum, maximum, diurnal temperature, and rainfall for the years 1990–2019 at a 95% confidence level are shown in Table 13. The overall trend of the above-mentioned climatic variables is shown in Figure 37 below. This graph represents the general picture of climatic variables for the Solan district, showing how temperature and rainfall vary during the phenological stages over the last 30 years.

Analysis of climatic parameters, such as minimum, maximum, diurnal temperature, and rainfall, revealed that the average maximum and diurnal temperature increased at rates of 0.001^{o}C and 0.036^{o}C per year, respectively, during the pre-flowering stage. whereas the average minimum temperature and annual rainfall decrease at the rate of -0.044^{o}C and -0.033mm per year, respectively. The *p* value for all the above variables was >0.005, hence none of them showed a significant result. Maximum temperature increased at a rate of 0.007^{o}C per year with a *p* value of 0.925 during the flowering stages, while minimum temperature increased at a highly significant rate of 0.151^{o}C per year with a *p* value of 0.001. In Kullu district, the yearly average minimum temperature for zone 2 increases by 0.89^{o}C each decade, and the average minimum temperature in February and March rises by approximately 1.12^{o}C and 0.97^{o}C, respectively, per decade (Kapoor and Shaban, 2014). The diurnal temperature during these phenological stages showed a highly significant decrease of -0.158^{o}C per year with a *p* value of 0.005 as shown in Table 4. The annual rainfall during the flowering stage was decreased significantly at-0.082 mm per year, which has a *p* value of 0.034 (significant). Similar observations were seen for the Sirmour district, where total rainfall in the period of 1991–2000 decreased over the years by 25.87 mm in spring and 86.90 mm in summer, while it increased in winter by 21.90 mm and 23.86 mm in autumn over the baseline period (Joshi and Verma, 2020).

Table 13 Illustrates the trend variation in climatic parameter during the three phenological stages i.e., pre-flowering, flowering, and fruit setting stages fruit crops of Solan district of HP

Phenological stages	Mean	Sen's slope	*p*- value
Pre-Flowering (February to Mid-March)			
Average Maximum Temperature	20.945	0.001	0.985
Average Minimum Temperature	6.089	-0.044	0.081
Diurnal Temperature	14.856	0.036	0.302
Annual Rainfall	8.741	-0.033	0.666

Flowering (Mid-March to April)			
Average Maximum Temperature	25.153	0.007	0.925
Average Minimum Temperature	9.653	**0.151**	**0.001**
Diurnal Temperature	15.499	**-0.158**	**0.005**
Annual Rainfall	2.792	-0.082	**0.034**
Fruit- Setting (May to June)			
Average Maximum Temperature	31.226	-0.040	0.171
Average Minimum Temperature	17.436	**-0.031**	**0.049**
Diurnal Temperature	13.790	0.013	0.666
Annual Rainfall	5.231	0.154	0.056

Values with Green color is highly significant and with red color is significant

Similarly, for fruit setting stages, these climatic variables showed varied results according to the analysis done. The average maximum and minimum temperature decreased at the rate of -0.040°C and -0.031°C per year, with a *p* value of 0.171 and 0.049 (significant) respectively. Meanwhile, the diurnal temperature and annual rainfall decreased at the rate of 0.013°C and 0.154 mm with a *p* value of 0.666 and 0.056 respectively. During the fruit setting stage, none of the climatic variables showed a significant change.

FRUIT CROP PRODUCTIVITY

Temporal analysis for the acreage, production, and productivity was done for the Solan district to study the trends. The trends are presented graphically to show how areas, production, and productivity have changed over a period from 1990 to 2019., the Mann-Kendall Test was performed for all the fruit crops of the Solan district. The outcome from this model tells us about the mean, magnitude of crop yield and level of significance as mentioned in Table 5. Among all the studied crops, a highly significant increase in productivity was observed for 9 fruit crops, while for the remaining 4 crops it was non-significant. The productivity of Plum, Peach, Apricot, Pear, Orange , Kagzi Lime, Galgal, Mango and Litchi increased highly significantly at the rate of 0.080 t ha^{-1} yr^{-1}, 0.027 t ha-1 yr-1, 1.071 t ha^{-1} yr^{-1}, 0.048 t ha^{-1} yr^{-1}, 0.016 t ha^{-1} yr^{-1}, 0.040 t ha^{-1} yr^{-1}, 0.044 t ha^{-1} yr^{-1}, 0.028 t ha^{-1} yr^{-1}, and 0.027 t ha^{-1} yr-1, respectively (Table 5). The temperate fruits like Pear, Peach, Plum, and Apricot showed an increase in production at the rates of 0.172, 0.064, 0.018, and 0.018 t/ha per year during the last ten years (Rana et al., 2017). Similarly, the productivity of Malta and Guava crops increased significantly in the Solan district, reaching 0.034 t ha-1 yr-1 and 0.034 t ha-1 yr-1, respectively. whereas the productivity of Apple was also increased non-significantly (0.007 t ha^{-1} yr^{-1}), while dry fruits in the district decreased non-significantly at -0.008 t ha^{-1} yr^{-1}. How much the climatic variations impacted the crops is explained in the next chapter, where a correlation with crop and climate has been calculated.

CLIMATE AND CROP CONNECTION

To observe the relationship between climate and the of crop, and the impact of climate change on the productivity of crop a Multivariate Linear Regression Analysis was done where the Pearson Coefficient and *p*-value were calculated for each climatic variable. Analysis revealed that during the pre-flowering stage, the crop productivity of only five crops viz., apple, malta, kagzi lime, mango and guava were significantly impacted by the climatic variables where one of two climate variables have a direct impact on the pre-flowering stage and ultimately in the crop yield. For apple, the average minimum and diurnal temperature showed moderate positive correlation i.e., .313 and .316 respectively. Similarly, for malta, the average diurnal temperature showed strong positive correlation i.e., .651 which impacted the pre-flowering stage by 52.6%. Likewise, for kagzi lime and mango, where average diurnal temperature showed moderate positive correlations i.e., .360 and .412 respectively (Table 3). In contrast, for guava a strong negative correlation i.e., -.526 was observed with average maximum temperature which ultimately impacted the pre-flowering stage by 55.3%. The total impact in terms of percentage was highest in the guava (55.3%), followed by malta (52.6%), mango (37%), kagzi lime (30.8%) and apple (25%) Table 3.

Similarly, for the flowering stage, malta showed significant strong positive correlations with average maximum (.730) and diurnal temperature (.623) where this phenological stage was impacted most (69.4%). Apple crop showed moderate positive correlation with average maximum temperature i.e., .320 which impacted the pre-flowering stage by 20.7%. On the other hand, guava showed strong negative correlation with average maximum and diurnal temperature i.e., -.631 and -.680 respectively which impacted the flowering stage by 56.5%. In nutshell, total impact on flowering stage was maximum for malta i.e., 69.4%, followed by guava (56.5%) and apple (20.7%) as showed in Table 4. Furthermore, fruit setting stage of mango was impacted most i.e., 39.2%, followed by plum (18.6%), pear (16.5%), malta (16.2%), and apple (12.5%) as shown in Table 5. However, the remaining crops of different phenological stages showed correlations with high *p* values hence, not explained.

CONCLUSION

The analysis of 30 years of climate and crop data revealed that during the pre-flowering stage, no significant variations were seen. Whereas for flowering stages, the minimum temperature increased significantly by 0.151°C per year, whereas the diurnal temperature during these phenological stages showed a highly significant decrease of -0.158°C per year. The annual rainfall during the flowering stage was also significantly decreased, at -0.082 mm per year. Although, for the fruit setting stage, the average minimum temperature decreased significantly at the rate of -0.031°C per year.

Findings from Mann-Kendall trend analysis revealed a highly significant increase in productivity for Plum, Peach, Apricot, Pear, Orange/Kinow, Kagzi Lime, Galgal, Mango and Litchi. A significant increase was seen for Malta, and Guava whereas non-significant variation was observed for Apple and dry fruits. Multivariate linear regression analysis for crop yields and climatic parameters revealed that the highest impact of climatic variables was observed for Malta and Guava, i.e., 44.4% and 42%, respectively, for the pre-flowering stage. During the flowering stage, the impact of climatic variables was highest for Malta (59.9%), followed by Guava (57.9%), Orange (49.6%), and Apricot (30.9%). whereas for the fruit setting stage, Mango had the highest percentage impact (60%), followed by Guava (33%), and Kagzi lime (29.5%). In general, each developmental stage of fruit crops is influenced by climatic variables, but in a positive way, which increases fruit crop productivity in the Solan district.

8. IMPACT OF CLIMATE CHANGE IN AGRICULTURE CROPS OF SOLAN DISTRICT, HIMACHAL PRADESH

The report provides a comprehensive assessment of climate change and its impacts on agriculture in the Solan district. Agriculture in Himachal Pradesh is a way of life agrarian population. A status study was conducted with a view to ascertain the impact of climate change on agricultural activities in district Solan. Seasonal trends on climatic variables i.e., minimum, maximum, and diurnal temperatures, and rainfall patterns were conjugated with a standardized anomaly index and a multivariate regression analysis conducted to unearth the climate and crop yield relationship for Kharif and Rabi season crops.

CLIMATIC TREND

Temperature (min, max, diurnal) and rainfall parameters are used as explanatory indicators to capture the pulse of climate variations in the district studied. The minimum, maximum and diurnal temperature revealed substantial changes during the Kharif and Rabi crop seasons for a period of 48 years, as per to statistical analysis, Mann Kendall trend test (table 14).

Table 14 Mann Kendall Test Results – Climatic Trends for Kharif and Rabi Season (1972-2019)

Climatic Parameters	Mean	Sen's slope	p-value
Kharif			
Max T	-0.021	-0.023	**0.020**
Min T	-0.014	-0.035	**<0.0001**
Diurnal T	0.009	0.026	**0.004**
Rainfall	0.019	-0.006	**0.287**
Rabi			
Max T	0.000	0.009	**0.271**
Min T	0.006	-0.035	**0.000**
Diurnal T	-0.004	0.038	**<0.0001**
Rainfall	**-1.552**	**-0.015**	**0.075**

During the Kharif season, the significant results were for maximum and minimum temperature which is decreasing at the rate of -0.023°C and -0.035°C per year respectively (as displayed by Sen's slope); while, diurnal temperature showing increase by 0.026°C per year. While, during Rabi season minimum temperature showed significant decrease by -0.035°C and increase in diurnal temperature by 0.038°C.

PRODUCTIVITY TREND

As per Mann Kandal Tests, the productivity trend for Wheat, Barley, Rice, Maize, and Total Pulses in the Solan district has considerably increased. Sen's Slope outcomes shows, Rice had the highest increase in productivity at 0.037t ha-1year-1, followed by maize at 0.030t ha-1year-1, wheat at 0.026t ha-1year-1, barley at 0.013t ha-1year-1, and total pulses at 0.012t ha-1year-1. The p-value for Wheat, Rice, Maize and Total Pulses is highly statistically significant which is <0.0001 whereas Barley has a statically significant p-value of <0.05.

CLIMATE CROP IMPENDENCY

To determine the relationship between the climate variability and agricultural productivity, a correlation analysis was performed.

CONCLUSION

During the 48 years (1972-2019) in Solan, the productivity for all crops were increased. The crops were least impacted by the climatic variables as results showed that Wheat was impacted 6.1%, Barley 2.1%, and Total Pulses 1.9% whereas the variables didn't show any significant correlation. While, Rice was impacted the most i.e., 13.4%, the diurnal temperature showed weak correlation with coefficient value .325 with non-significant *p* value i.e., .012. The significant results were found only for the Maize, a weak correlation with coefficient value .175 and significant *p* value i.e., .004. In Solan district for agriculture crops other factors may be responsible for the increase in the productivity such as whereas the climatic parameters concluded very less.

9. IMPACT OF CLIMATE CHANGE ON HORTICULTURE CROPS OF BILASPUR DISTRICT, HIMACHAL PRADESH

CURRENT CLIMATE TREND

Temperature and precipitation are regarded as primary markers of climate change in the Bilaspur district. Based on the statistical analysis, Mann Kendall trend test extremely insignificant changes in climatic variables was observed during all the phenological stages. Analysis of climatic parameters, such as minimum, maximum, diurnal temperature, and rainfall of Bilaspur district, revealed that the average minimum temperature and annual rainfall increased at rates of 0.065℃ and 7.200mm per year respectively, during the pre- flowering stage. whereas the average maximum temperature and diurnal temperature decreaseat the rate of -0.415℃ and -0.320℃ per year, respectively. The *p* values for all the above variables were > 0.05, hence none of them showed a significant result.

CROP PRODUCTIVITY TREND

Among all the studied crops, a highly significant increase in productivity was observed for 2 fruit crops (Mango and Orange). **The productivity of Mango and Orange increased highly significantly at the rate of 0.030 t ha^{-01} yr^{-1}, and 0.006 t ha^{-1} yr-1, respectively** and for the Kagzi Lime and Dry fruit it was increased non-significantly. While for the Pear and Galgal productivity decreases non- significantly.

CLIMATE FRUIT CONNECTION

30 years of horticulture data including production, acreage and 7 years of temperature data (2014–2020) of the Bilaspur district were analyzed by using statistical tools such as the Standardized Anomaly Index (SAI), the Mann Kendall Test, and Multivariate Linear Regression Analysis. Six fruit crops were assessed, viz., Pear, Dry Fruits, Orange, Kagzi Lime, Galgal, Mango. Multivariate linear regression analysis for crop yields and climatic parameters revealed that the highest impact of climatic variables was observed for Dry fruit and Orange i.e., 88.2% and 59%, respectively, for the pre-flowering stage. During the flowering stage, the impact of climatic variables was highest for Dry fruit crop (87.8%), followed by Pear (66.6%), and Kagzi Lime crop (62.5%). whereas for the fruit setting stage, Kagzi Lime crop had the highest percentage impact (93.3%), followed by Galgal crop (90.2%). In general, each developmental stage of fruitcrops is influenced by climatic variables, but Orange and Mango crop has been influenced by climatic variables in a positive way, which increases fruit crop productivity of these crops in the Bilaspur district.

10. IMPACT OF CLIMATE CHANGE ON HORTICULTURE CROPS OF HAMIRPUR DISTRICT, HIMACHAL PRADESH

CURRENT CLIMATE TRENDS

Temperature (minimum, maximum, diurnal) and rainfall were employed as explanatory indicators to capture the essence of climatic variations in the Hamirpur district of Himachal Pradesh in order to evaluate the influence of climate change in the area. A highly significant shift in climatic factors was noticed during the pre-flowering season, flowering season, and fruit setting season, according to the statistical analysis, Mann-Kendall trend test. The Mann-Kendall test findings Showed observation for minimum, maximum, diurnal temperature, and rainfall for the years 2014–2020 at a 95% confidence level. Analysis of climatic parameters, such as minimum, maximum, diurnal temperature and rainfall revealed that the average maximum and diurnal temperature decreased at rate of 0.240^{o}C and -0.303^{o}C per year, respectively during the pre-flowering stage. Whereas, the average minimum temperature and annual rainfall decreased at the rate of 0.0001^{o}C and – 7.500mm per year, respectively. The *p* value for all the above variables was >0.005, hence none of them showed a significant result. Maximum temperature decreased at a rate of -0.517^{o}C per year with a *p* value of 0.719 during the flowering stages, while minimum temperature increased at the rate of 0.0001^{o}C per year with a *p* value of (1.000). The diurnal temperature during these phenological stages showed a decrease of -0.375 o C per year with a *p* value of 0.719. The annual rainfall during the flowering stage didn't show any significant variation, which has a *p* value of 1.000 (non-significant). Similarly, for fruit setting stages, these climatic variables showed varied results according to the analysis done. The average maximum, minimum temperature and diurnal temperature increased at the rate of 0.283 ^{0}C, 0.117 ^{0}C and 0.150 ^{0}C per year, with *p* value of 0.719, 0.444 and 0.719 (non-significant) respectively.

CROP PRODUCTIVITY TRENDS

The Mann-Kendall Test was performed for all the fruit crops of the Hamirpur district and analysis revealed that the productivity of Plum and Pear increased highly significant at the rate of 0.013 t ha^{-1} $yr^{-1}$and 0.086 t $ha^{-1}yr^{-1}$ respectively. The productivity of Kagzi Lime and Galgal, increased significantly at the rate of 0.004 t ha^{-1} yr^{-1} and 0.051t ha^{-1} yr^{-1} respectively. Whereas, the productivity of Mango was slightly increased non-significantly (0.010 t ha^{-1} yr^{-1}), while dry fruits in the district decreased non-significantly at the rate of -0.001 t ha^{-1} yr^{-1}.

CLIMATE FRUIT CORRELATION

Multivariate linear regression analysis for crop yields and climatic parameters revealed that the highest impact of climatic variables was observed for Pear, Plum and Dry fruits, i.e., 95.4%, 94.9 and 81.9%, respectively, for the pre- flowering stage. During the flowering stage, the impact of climatic variables was highest for Mango (92.9%), followed by Plum (67.6%), K. Lime (39.1%), and Galgal (35.9%). Similarly, for the fruit setting stage, Mango had the highest percentage impact (62.6%),followed by Plum (60.2%), and Dry fruits (47.9%).

PUBLICATIONS

RESEARCH PAPERS

- Rathore, B. & Bahuguna, Ishmohan & Singh, S. & Gupta, Ujjwal & Randhawa, Surjeet. (2022). Monitoring snow cover in the Himalayan– Karakoram basins using AWiFS data: significant outcomes. Current Science. 122. 1305-1314.
- Priyanka Sharma, Harish Bharti, Aditi Panatu, S.S. Randhawa, R.S. Rana and Nishant Thakur. (2022) Impact of Climate Change on Agriculture Production in District Kinnaur, Himachal Pradesh. Journal of Biodiversity. Vol. 13(1-2): 14-23 DOI: 10.31901/24566543.2022/13.1-2.104.

BROCHURES

- Assessment of Spatial Distribution of Seasonal Snow Cover during year 2021-22 in Himachal Pradesh using AWiFS Satellite data
- Vulnerability of Himachal Pradesh from Climate Induced Hazards (GLOFs)

BOOKLET

- Booklet on **“Assessment of Spatial Distribution of Seasonal Snow Cover during year 2021-22 in Himachal Pradesh using AWiFS Satellite data”**

WORKSHOPS/TRAININGS/SURVEY

11. THREE DAY TRAINING PROGRAMME ON “SAFE HILL AREA DEVELOPMENT” IN HIMACHAL PRADESH

Training programme on *“Safe Hill Area Development”* was organized by Himachal Pradesh Council for Science, Technology & Environment (HIMCOSTE), Shimla in collaboration with National Institute of Disaster Management (NIDM), Ministry of Home Affairs, Govt. of India, New Delhi. This training program was organized at State Agriculture Management & Extension Training Institute (SAMETI), Mashobra, Shimla from 15th to 17th June, 2022 from 10:00 am to 5:00 pm for a total duration of seven hours. The sessions generated highly interactive, easily understandable points of action and implementation by individuals having responsible role in ULB, as Govt. stakeholder or as any responsible citizen. The course highlighted the importance of building resilience, preparedness, and mitigation measures to achieve the resilient urban environment through city disaster management planning.

KEY POINTS OF TRAINING PROGRAMME

- The capacity, vulnerabilities, and resource availability of the town must be evaluated.
- In addition to increasing the intensity and frequency of catastrophes, climate change influences health, transportation infrastructure, and lifeline facilities. Due to this, the effects of disasters and those of climate change must be combined.
- Cities that are rapidly expanding have a rising number of structures that are sub standardly built or poorly maintained, which causes avoidable fatalities. Although urbanisation is inevitable, efficient urbanism is necessary.
- Create a disaster risk reduction action plan to lessen the possibility of harm, fatalities, and financial loss in the event of a hazard or catastrophe.

- The Emergency Operation Center's importance for efficient coordination and communication should be there.
- The significance of a thorough risk analysis in creating a city development plan.
- With the aid of robust infrastructure and funding systems, as well as by understanding vulnerabilities, potential causes and effects, economic and social impacts, mitigation plans, preparedness, and response, one can resist and reduce risks by concentrating on urban planning and sustainable development.
- To increase knowledge, it is important to promote building regulations and construction methods that adhere to the requirements established by the relevant authorities.
- By using disaster risk management techniques, such as a fire detection and safety alarm system with automated water sprinklers to douse the flames, risks can be reduced.
- Installation of fire pumps in potential locations to facilitate the dispatch of emergency services.
- Encourage the use of fire-resistant building materials, water-powered fire extinguishers inside the structure, and public education about evacuation procedures.
- To lower the amount of risk, a community or organisation should develop its human resources or social infrastructure. Establish financial institutions and infrastructure to withstand calamities and aid.
- To reduce the risk of urban flooding, the best drainage and sewerage schemes must be implemented.
- zoning and shielding the watershed and natural drainage systems from habitation.
- hotspot analysis, service prioritisation, and development activity prioritisation.
- Everyone should be familiar with their local location, the current water level, and city danger maps. To assess the impact, it is important to determine the population density.
- High-rise structures and all school buildings should have automatic smoke and fire alarm systems built in.

- To strengthen the resilience of our school infrastructure, we should pursue preventative strategies for new building.
- To further protect outdated essential infrastructure from earthquake risk, retrofitting procedures should be undertaken for identified old and weak structures such as columns and joints.

12. ONE DAY WORKSHOP ON "SENSITIZATION OF POLICY MAKERS & ADMINISTRATORS ON CLIMATE CHANGE AND ITS IMPACT ON MOUNTAIN ECOSYSTEM

In order to address the issues arising out of the climatic variations, it is very important to sensitize the different organs of the Government about the climate change. One-day workshop on "Sensitization of Policy Makers and Administrators on Climate Change and its Impacts on the Mountain Ecosystem" was organized on 30th June, 2022 at Hotel Holiday Home, Shimla, organized jointly by State Climate Change Centre (CCC) under the aegis of Himachal Pradesh Council for Science Technology and Environment, Shimla and the Divecha Centre for Climate Change, Indian Institute of Science (IISc) Bangalore. The workshop was organized to discuss about the current and future scenario of climate change in Himalayan region and throughout the world. This workshop indeed was a great success and administrators including policy makers attended the workshop enthusiastically giving their personal perceptions and inputs regarding climate change.

MAJOR RECOMMENDATIONS

Some of the major recommendations emerged out of the deliberations and discussions during the workshop are:

- SCCC of the HIMCOSTE and the Divecha Centre for Climate Change shall evolve a mechanism for the outreach program to the society in a joint mode to create awareness about the climate change and its various impacts on the mountain ecosystem. This should be taken should be in the campaign mode and SCCC in consultation with Divecha Centre for Climate Change will carry forward this on priority.

- H.P. State Centre on Climate Change (SCCC), Divecha Centre for Climate Change (DCCC) and Indian Institute of Climate Change (IITM) will explore possibilities for further research avenues in climate change depending upon the funding provisions available with either of the institutions and take up further in joint mode.
- Mainstreaming climate change adaptation into policy-making, budgeting, implementation, and monitoring processes at all different levels.
- High altitude regions of Himachal Pradesh are expected to experience higher rise in temperature than the global mean and low altitude therefore special attention is need to understand the climate change of Himalaya.
- Winter snowmelt can reduce soil moisture in spring and summer seasons, increasing forest fire incidences. Therefore, improvement in forest fire management strategy is needed.
- Winter snow melt may lead to early drying of mountain springs. Therefore, spring rejuvenation plan needs to be developed.
- Retreating glaciers and early melting of snow can change the runoff pattern of mountain streams. Therefore, improvement in small hydropower development strategy and plant design is needed.
- Retreating glaciers can cause formation of new glacier lakes and expansion of existing ones. Therefore, vulnerability assessment of each lake is needed.
- Climate change expected to increase frequency of heavy precipitation which will lead to flash floods. Therefore, early warning system and flood management strategy needs to be strengthened.


13. TRAINING OF MASONS ON HAZARD RESISTANT CONSTRUCTION AT APPROPRIATE TECHNOLOGY CENTRE, SUNDERNAGAR BLOCK DISTRICT MANDI AND GRAM PANCHYAT NIHRI, DISTRICT MANDI, H.P.

INTRODUCTION

Training of masons on hazard resistant construction was organized in a series at Appropriate Technology Centre, Sundernagar Block, District Mandi and Gram Panchayat Nihri, Up-tehsil Nihri, district Mandi, H.P. in collaboration with State Disaster Management Authority (SDMA), Shimla, H.P. under the guidelines of National Disaster Management Authority (NDMA), GoI. The three days training programme was organized w.e.f. 16th to 18th December 2021 and 15th March to 17th March 2022 respectively. A total of 40 masons in ATC Sundernagar and 33 in Gram Panchyat Nihri were trained under this programme.

This training made masons aware not only of the critical principles of hazards resistant construction but also provide some practical skills in appropriate and relevant details of Rural Housing Technologies that people use in different regions of India. The objective of this training curriculum is to strengthen the practicing Masons on Hazard Resistant Construction Techniques and features through theoretical and practical sessions.

This training is meant to guide Masons on construction of engineered houses up to two stories and does not cover construction of engineered buildings with reinforced concrete frame for multi storey buildings.

TRAINING METHODS

This training module was envisaged to be for 3 days. Each training day was designed such that there would be ample time for hands-on training of Masons. The classroom sessions were planned using participatory methods with discussions, audio visual presentations models etc. Sessions provided enough time and scope for the trainees to discuss their concerns, questions and issues. The practical construction sessions were to get hands-on experience of hazard resistant features and details used in construction work.

14. QUESTIONNAIRE BASED SURVEY ON "IMPACT OF CLIMATE CHANGE IN AGRI-HORTI AND FORESTRY SECTOR IN HIMACHAL PRADESH

A questionnaire-based survey was conducted in the Mandi district of Himachal Pradesh to assess the impact of climate change and the adaptation strategies in the district. This survey took 10 days i.e., November 21 to 30, 2022 to complete the entire district. The blocks covered under survey were Gopalpur, Dharampur, Chauntra, Drang, Mandi Sadar, Balh, Sunder Nagar, Seraj and Karsog. We randomly selected the neighboring villages of the development blocks to complete the sample size which ranges from 60-90 individuals per block. The total no. of individuals covered under this survey was 605.

GENERAL OBSERVATIONS

- Climate change has huge impact, and the reason of climate change is majorly human activities.
- **Increased parameters-** landslides, temperature, drought, frost, irregular rainfall.
- **Decreased parameters-** decreased access to fresh water *(decreased level of water in river/stream/well),* water quality and hail frequency.
- **Crops grown 30-40 years ago-** Wheat, barley, mustard, black gram, masoor, paddy, maize, finger millet, Ginger, turmeric, chilies, tomatoes.
- **Present Crops-** Wheat, potato, barley, maize, paddy, millets, (**ginger, turmeric, chilies, tomatoes, capsicum, bean, soybean- less grown crops).**
- Due to drought conditions, stray and wild animal menace, pulses and vegetables are not grown. Therefore, the agriculture fields are converted into forests. Hence, timber requirement of the people is fulfilled form the agriculture fields therefore, less dependency on forests resources. **In general, forests have been increased.**
- Traditional crops are not grown due changing in food preferences, difficulty in processing, low production etc.
- The quality of produce of improved/hybrid varieties is increased but the local varieties has been greatly reduced. Disease incidence and insect pest attack has been increased and the population of pollinator is decreased.
- **Diseases:** The major disease increased in the district are black and yellow rust of wheat, leaf blight, leaf spot, rust, and bacterial wilt are very common. Stem borer of maize, paddy, cut worms and aphids are very common pest infestation.
- **Adaptation strategies:** People are changing crop varieties and most of them growing short season crops and planting fruit/nut trees. Most of the respondents are using chemical fertilizers

and spray. People are not growing resilient and drought resistant varieties due to the lack of information. There are no water harvesting schemes adopted by the people since there is no any irrigation facilities and people are finding off-farm jobs.




FIELD VISITS

TRAINING PROGRAMME ON CRYOSPHERIC APPLICATIONS USING REMOTE SENSING

The training programme was organized at SAC, ISRO Ahmedabad w.e.f. 24th July 2022 to 7th August 2022. The following lectures/hands on training were attended under the training programme:

- Lecture on **"Basics of Remote Sensing"**
- Lecture on **"Pre-processing of Remote Sensing data"**
- Tutorial and hands on training on **"Identification and Mapping of Mountain Snow/Glacier using Optical and Microwave Data"**
- Lecture on "**Current Trends in GIS"**
- **"Development of Optical and Thermal RS Sensor"**

- "**Development of Microwave RS Sensor"**
- "**Remote Sensing of Cryosphere"**
- **"Himalayan Snow and Glacier Studies at SAC"**
- **"Microwave and Hyperspectral Remote Sensing Data"**
- **"Glacier Dynamics: Mountain and Polar Cryosphere"**
- **"Glacier Mass Balance" & "AI/ML in EO Applications"**
- Tutorial and hands on training on **"Glacier Ice Velocity and DEM"**
- "**Polar Ice Sheet Studies", **"**Sea Ice Monitoring and PolSAR Applications for Cryosphere"**
- Tutorial and hand on training on "**Polar ice sheet studies"**
- Exposure visits to Vikram Sarabhai Space Exhibition Centre
- **"WRF-Hydro: Application in Snow Hydrology"**

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State Centre on Climate Change

Annual Progress Report

2022-23

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