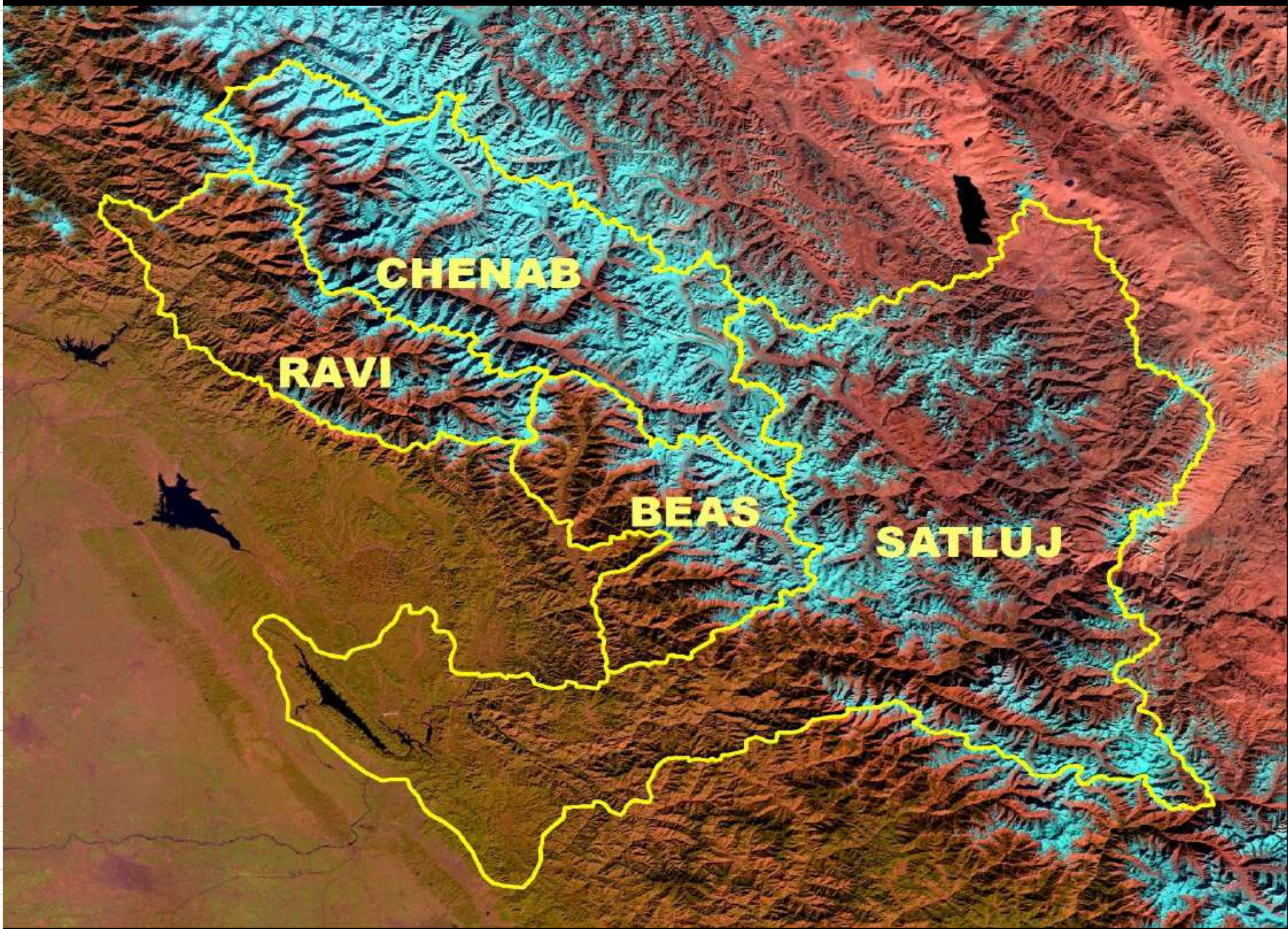
Assessment of Spatial Distribution of Seasonal Snow Cover during the Year 2022-23 in Himachal Pradesh Using AWIFS Satellite Data



State Centre on Climate Change (SCCC)

H.P. Council for Science Technology & Environment (HIMCOSTE)

Vigyan Bhawan, Bemloe, Shimla-1

&

Space Applications Centre (ISRO) Ahmedabad

Geo-Sciences, Hydrology, Cryosphere Sciences and Applications Group (GHCAG)

Department of Space, Govt. of India, Ahmedabad

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Abstract	Climate Change issues are of global concern but it pose major challenge to our mountain environment as mountain ecosystem is highly vulnerable and sensitive to the climatic variations. Mountains have special role in showing the effects of climate change. The Himalayan ecosystem has 51 million people who practice hill agriculture and whose vulnerability is expected to increase on account of climate change Glaciers in the Himalaya have been reported to be retreating, which could lead to water scarcity in the future for people living in the mountain region and downstream areas that rely on glaciers and snow for fresh water. Retreating glaciers, depleting snow cover and Glacial Lake Outburst Floods (GLOFs) are of immediate concern in the mountain environment as GLOFs can have a devastating impact on hydro power, water sources, people, livestock, forests, farms and infrastructure. Decreases in snow accumulation and glacial retreat might lead to acute water shortages in the future. 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 was carried out in different river basins in Himachal Pradesh during the winter season of 2022-23 from October to April. 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 obtained for the 2022-23 winter suggest that there was an overall decrease in the monthly averaged area under snow cover during 2022-23 (October-April) by about 14%, which was positive (19%) during the last winter (2021-22). During 2022-23 winter, the snowcover shows negative results in all the months except October & Novermber , where as during peak winter months, the trend was totally negative. During early summer i.e in April, there was a sudden rise in the area under snow due to late snowspells . The temperature trend analysis was also carried out from 2018-23 , mean maxium and minimum average temperature shows an incresing trend in almost all the basins based on ITA and PBIAS methods.
Security classification	Unrestricted

PREFACE

During the geological history, the earth has experienced alternate cycles of warm and cold climates. During cold climate, glaciers and ice sheets were formed on the surface of the earth. In Himalaya, glaciers cover approximately 33000 sq. km area, and this is one of the largest concentrations of glacier-stored water outside the Polar Regions. Melt water from these glaciers forms an important source into run-off of North Indian Rivers during critical summer months. This makes these rivers perennial and has helped to sustain and flourish the Indian civilization along the banks of Ganga and Indus. Melt water from these frozen masses also forms the important source for hydropower development over the Himalayan region and the sustainability of the Himalayan bio diversity and the environment.

Mountain systems are particularly sensitive to climate changes. Although Climate Change issues are of global concern, it poses major challenge to our mountain environment as mountain ecosystem is highly vulnerable and sensitive to the climatic variations.

The snow and glaciers in the cryosphere have a great significance to understand the water security from the drinking and irrigation perspective besides the sustainability of the hydro power in the Himalayan region. Besides this, the cryospheric studies are also important from the climate point of view as the snow and glaciers are considered to the direct indicators of the climate change, but such studies over Himalayan region are difficult using conventional methods by virtue of its topography, accessibility and the other extreme weather events.

The technical document prepared by the State Centre on Climate Change under the aegis of the Himachal Pradesh Council for Science Technology & Environment on **Assessment of Spatial Distribution of Seasonal Snow Cover during the Year 2022-23 in Himachal Pradesh Using AWIFS Satellite Data** mainly depicts the changing snowfall patterns over Himachal Himalaya during the past and its spatial variability in different river basins of the State. I am sure, this document would be useful for the scientific and academic community, HPSEBL, HPPCL, SJVNL and other private entrepreneurs operating in the hydel sectors in the State to make an assessment about the changing snow cover in their catchments and the discharge dependability in the peak time. I appreciate the efforts made by the State Centre on Climate Change and the Space Applications Centre (ISRO) Ahmedabad for undertaking the cryopsheric studies over the Himalayan region to understand the impact of climate change on this issue of vital importance in the present era of climatic variations wherein the Himalayan region are facing great challenge.

Prabodh Saxena, IAS
Chief Secretary (GoHP) &
Chairman (HIMCOSTE)

FOREWORD

The economy of State is wholly dependent on areas like the hydel power generation, horticulture, agriculture, forestry and tourism and are assumed to be under threat in the present scenario of changing climate. Any change in these sectors due to climate change, in every likelihood, will not only going to affect the livelihood prospects in the agrarian economies of mountain regions, but also everyone living below in the plains.

Glaciers in the Himalaya have been reported to be in the retreating phase and in future, this can result in water scarcity for the people living in the mountain region and in downstream area who depend on glaciers and snow as a source of fresh water. Retreating glaciers, depleting snow cover and Glacial Lake Outburst Floods (GLOFs) are of immediate concern in the mountain environment as GLOFs can have a devastating impact on the hydro power, water sources, people, livestock, forests, farms and infrastructure. Decreases in snow accumulation and glacial retreat might lead to acute water shortages in the future.

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 ablations patterns of the glaciated regions in the State.

The cryospheric studies over Himalayan region have a great significance from State's perspective but the studies using conventional methods are difficult because of various technical issues. Satellite data by virtue of its synoptic coverage, distinct spectral properties, high temporal frequency and with the advancements in the technology, SAC has evolved various applications for the mapping of snow and glaciers, seasonal snow cover mapping, mapping of moraine dammed lakes and mass balance studies by using satellite images of different resolutions, it has now become possible to undertake various cryospheric studies with much more accuracy and reliability.

The State Centre on Climate Change under the aegis of the Himachal Pradesh Council for Science Technology & Environment has been involved in carrying cryospheric studies for more than last two decades in association with Space Applications Centre Ahmedabad (SAC-ISRO) and has generated lot of data in the field of snow and glaciers in Himachal Himalaya. The present technical report on **Assessment of Spatial Distribution of Seasonal Snow Cover during the Year 2022-23 in Himachal Pradesh Using AWIFS Satellite Data** illustrates about the spatial distribution of seasonal snow fall in different rivers basins like Chenab, Ravi, Beas and Satluj in Himachal Himalaya during the 2022-23 winter period and its temporal variation with that of 2021-22 winter period. I hope the findings would be useful for the stakeholders operating in the hydel sector and the academicians and scientists to make an assessment about the climate change impacts over mountain region. I complement the efforts made by the entire team of HIMCOSTE and Space Applications Centre Ahmedabad in this compilation.

D.C.Rana, IAS
Director (Env. Sci. & Tech) GoHP -cum-
Member Secretary (HIMCOSTE)

Seasonal Snow Cover Variations in Himachal during 2022-23 and its comparative analysis with reference to 2021-22.

1. 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.

1.2 Methodology

1.2.1 Normalized Difference Snow Index (NDSI):

Normalized Difference Snow Index (NDSI) utilize the normalized ratio of green and SWIR and was used as an automated approach for snow mapping addressing the shadow and cloud problems in snow bound areas.

Normalized Difference Snow Index was calculated using the ratio of green wavelength (band 2) and SWIR (band 5) of AWiFS sensor:

Normalised Differential Snow Index (NDSI) = (band2 - band5) / (band2 + band5) eq.1

To estimate NDSI, digital numbers (DNs) were converted into top-of-atmosphere reflectance. This involves conversion of DNs into the radiance values, known as sensor calibration, and then reflectance was estimated. The various parameters (e.g., maximum and minimum radiances, mean solar exo-atmospheric spectral irradiances in the satellite sensor bands, satellite data acquisition time, solar declination, solar zenith and solar azimuth angles and mean Earth–Sun distance) were used to estimate reflectance (Markham and Barker, 1987; Srinivasulu and Kulkarni, 2004). Sensitivity analysis has shown that a NDSI value of 0.4 can be taken as a threshold to differentiate between snow and non-snow pixels. Exo-atmospheric reflectance of bands 2 and 5 of the AWiFS sensor was used to compute the NDSI, and no atmospheric correction has been applied at present. Field investigations suggest that NDSI values are independent of illumination conditions, i.e., snow/non snow pixels can be identified under different slopes and orientations, even under mountain shadow region (Kulkarni et al., 2006).

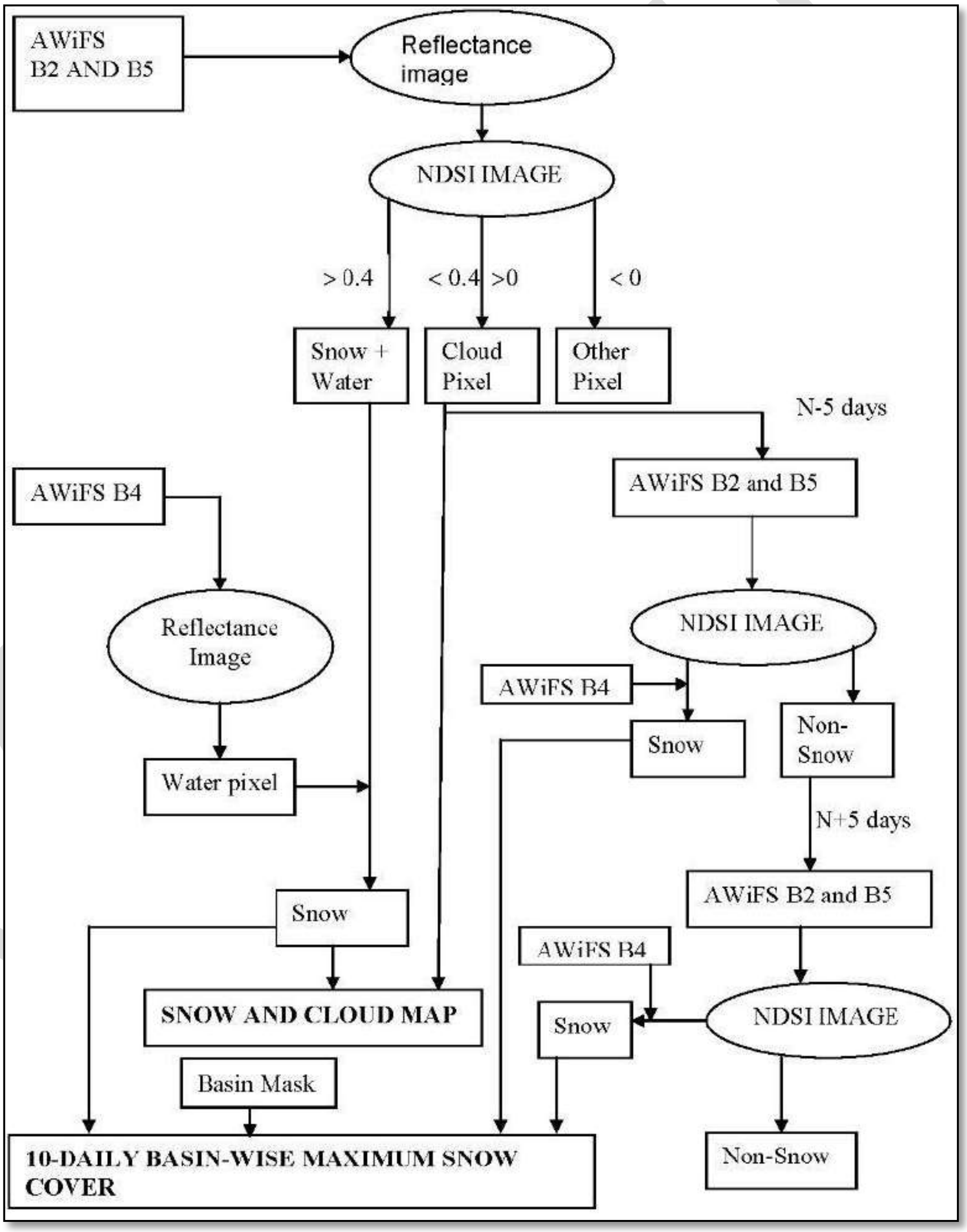


Fig.1.1 Algorithm for snow cover mapping using AWiFS data

Snow cover extent is generated scene-wise. In this product, snow and cloud extents are given. Estimate of cloud is important because, at times, snow is covered by cloud and this may be classified as non-snow area, leading to erroneous conclusions.. If any pixel is identified as snow on any one date then this pixel will be classified as snow on final product. Therefore, this product is generated basin-wise. AWiFS data has been used for calculating area monitoring algorithm.An algorithm is developed to provide changes in the areal extent of snow (Kulkarni et. al., 2006).

1.2.2 Trends in Maximum and Minimum Temperature Analysis

To identify trends in this work, two methods ITA (Innovative Trend Analysis) and percent bias (PBIAS) were used. The data for this work was collected from the IMD (Indian Metrological Department). Only maximum and minimum temperature of the snow accumulation months of October to April for the year 2018 to 2023 were used for the analysis.

The data collected was checked for missing values, typographical errors and maximum temperature values to be more than minimum temperature values. The missing values were found to be less than 10%. These values were replaced using multiple imputation approach. The data collected was divided into two equal parts for the ITA and PBIAS calculation. A brief description of these methods is given in the following sub-section as follows: -

ITA (Innovative Trend Analysis) - ITA is a graphical non-parametric time series analysis method proposed by Sen (2012). It is capable of detecting the monotonic trend as well as sub-trend in the time series datasets through the recognition of trends of low, medium and high values of hydro-climatic or hydro-meteorological variables accurately (Das et al. 2021 and PZ & KV, 2021). The main advantage with this method is that it does not involve assumptions like non-normality, serial correlation and sample number.

To perform ITA several steps are followed. At first, data are splitted into two equal parts and are then arranged in ascending order. In the second step, both parts are plotted against each other graphically representing first half on the x-axis and second half on the y-axis. In the third and final step, straight line is fitted within the scatter plot representing monotonic trend, no trend or non-monotonic trend. If the scatter lies above the trend less line (45o line) it denotes increasing trend whereas the concentration of the scatter below this line exhibit decreasing trend. The concentration of the scatter on the trend less line (45° line) indicates no-trend.

The slope of IT was also calculated to know the magnitude of the change from the following equation proposed by Sen (2012) –

$$B = \frac{1}{n}\sum_{n}^{i=1} \frac{10\left(x_j - x_k\right)}{\bar{x}} \qquad \text{eq.2}$$

Where S_1 represents the ITA slope, n denotes the extent of individual sub-series, x_j and x_k represents the values of the consecutive sub-series and $\bar{x}$ indicates the mean of the first half (x_k).

PBIAS (Percent Bias) – PBIAS method is used to estimate the percentage of change in climatic variables between the 1st and 2nd half of the time-series. This is calculated from the equation proposed by Mandal et al. (2020) as per equation 2. The positive values are indicative of increasing trend, whereas negative values of decreasing trend with respect to first sub-series.

$$P_{BIAS} = 100 - \sum_{i-1}^{n} \frac{Yi}{Xi} \times 100 \qquad \text{eq.3}$$

Where PBIAS represents the percent bias, n denotes the total length of each sub-series and X_i and Y_i are the observed data values in the first and second sub-series, respectively.

2. 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

2.1 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. On analysing the satellite data for the month of October 2022-23, it is found that the total area under seasonal snow cover in the Chenab Basin has been decreased by about 36% i.e. the area under snow in the month of October which was mapped as 7111.15 Km^2 in 2021-22 has been redcued to 4544.44 Km^2 . Likewise in November, an increase of about 5% was noticed in comparision to 2021-22 i.e. the surface area mapped as 6748.01Km^2 (2021-22) has been increased to 7116.32 Km^2. During the peak winter months (December to February) i.e. December, a reduction of about 10% could be obserevd in the entire catchment of Chenab basin i.e the surface area under snow mapped as 7593.06 Km^2 (2021-22) reduced to 6843.02 Km^2 (2022-23) and in January, a reduction of about 5% could also be seen i.e. the surface area mapped as 7973.85 Km^2 (2021-22) reduced to 7582.3 Km^2 (2022-23) . Likewise in February a reduction of about 4% was observed in the total area under snow i.e the area under snow mapped as 8577.66 Km^2 (2021-22) has been reduced to 8231.34 Km^2 (2022-23) . Likewise in March about 2% decrease in area under snow was observed in 2022-23(7701.42 Km^2) in comparison to 2021-22 (7834.82 $Km^{2)}$. Likewise in April 2022 which is the generally the beginning of the summer season but the area udner snow has increase and shows an increse of about 23% in the total area under snow i.e. area under snow in 2021-22 (5671.99 Km^2) has increased to 7328.86 Km^2 (2022-23). Thus 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 slightly 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. 2.1.1, 2.1.2 & Table 2.1.1).**

Table 2.1.1: 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	29.21
	Avg. Total	**7357.22**	**7049.67**	**82.33**	**-4.18**

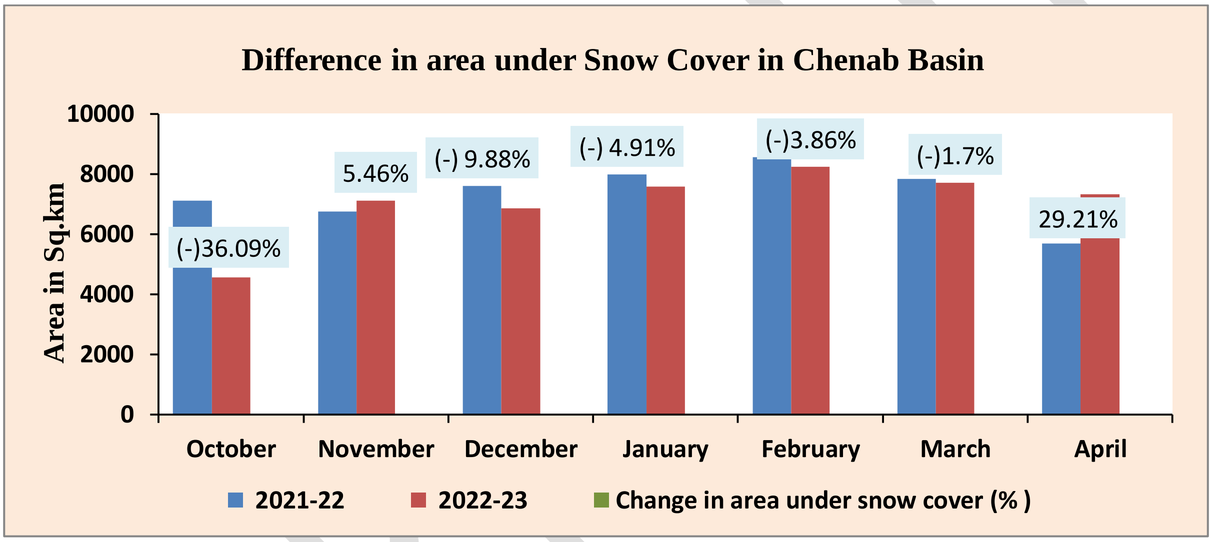


Fig. 2.1.1: Difference in area under Snow cover in Chenab Basin

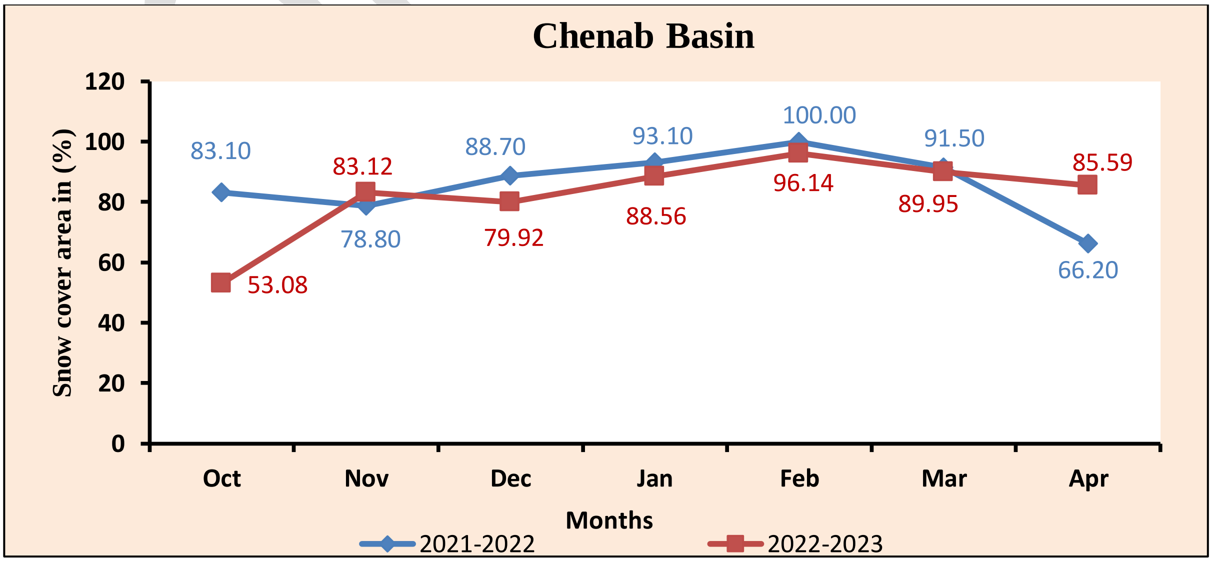
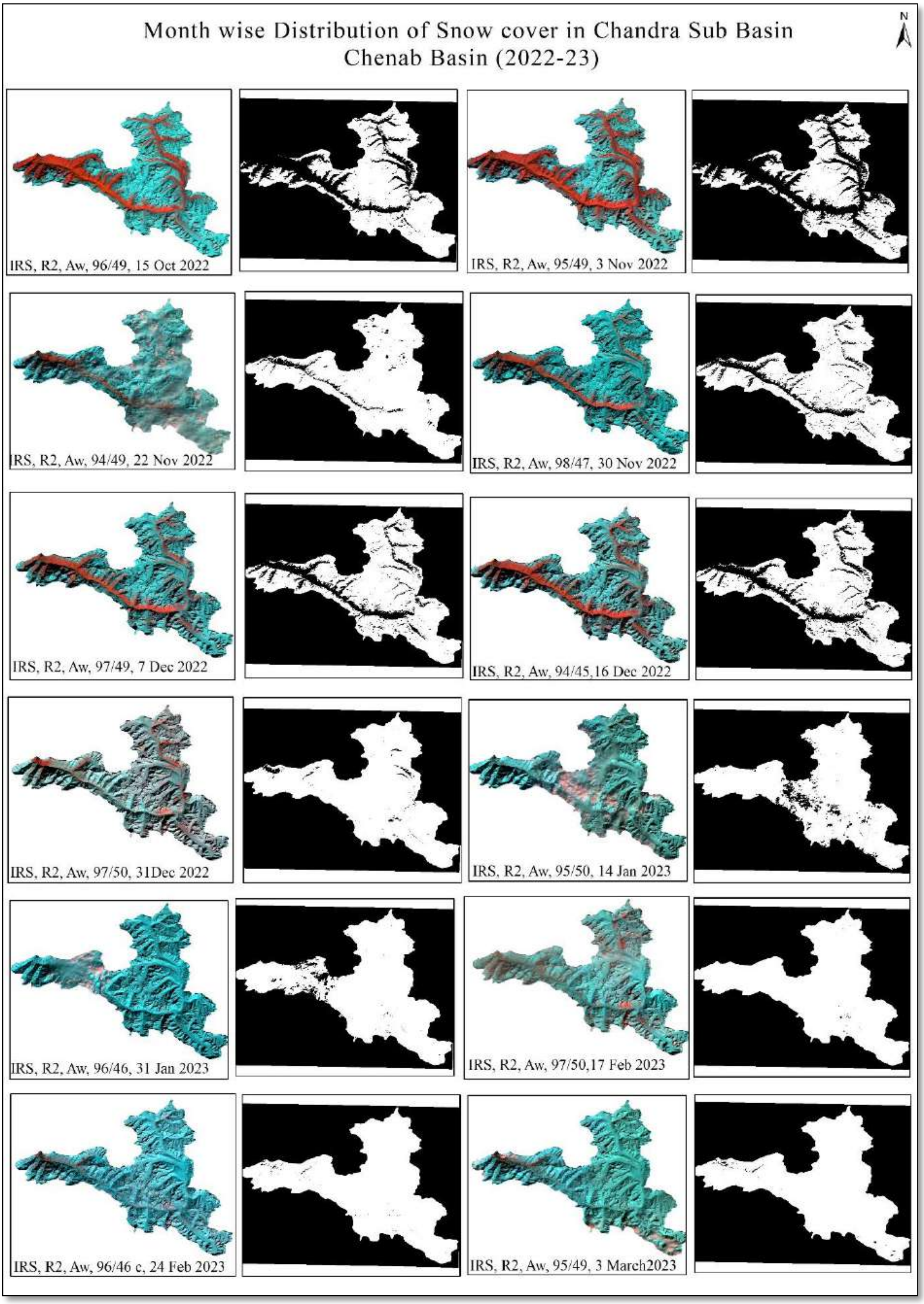


Fig. 2.1.2: Area under Snow cover (%) in Chenab Basin


Month wise Distribution of Snow cover in Chandra Sub Basin
Chenab Basin (2022-23)
N
IRS, R2, Aw, 96/49, 15 Oct 2022
IRS, R2, Aw, 95/49, 3 Nov 2022
IRS, R2, Aw, 94/49, 22 Nov 2022
IRS, R2, Aw, 98/47, 30 Nov 2022
IRS, R2, Aw, 97/49, 7 Dec 2022
IRS, R2, Aw, 94/45,16 Dec 2022
IRS, R2, Aw, 97/50, 31Dec 2022
IRS, R2, Aw, 95/50, 14 Jan 2023
IRS, R2, Aw, 96/46, 31 Jan 2023
IRS, R2, Aw, 97/50,17 Feb 2023
IRS, R2, Aw, 96/46 c, 24 Feb 2023
IRS, R2, Aw, 95/49, 3 March2023

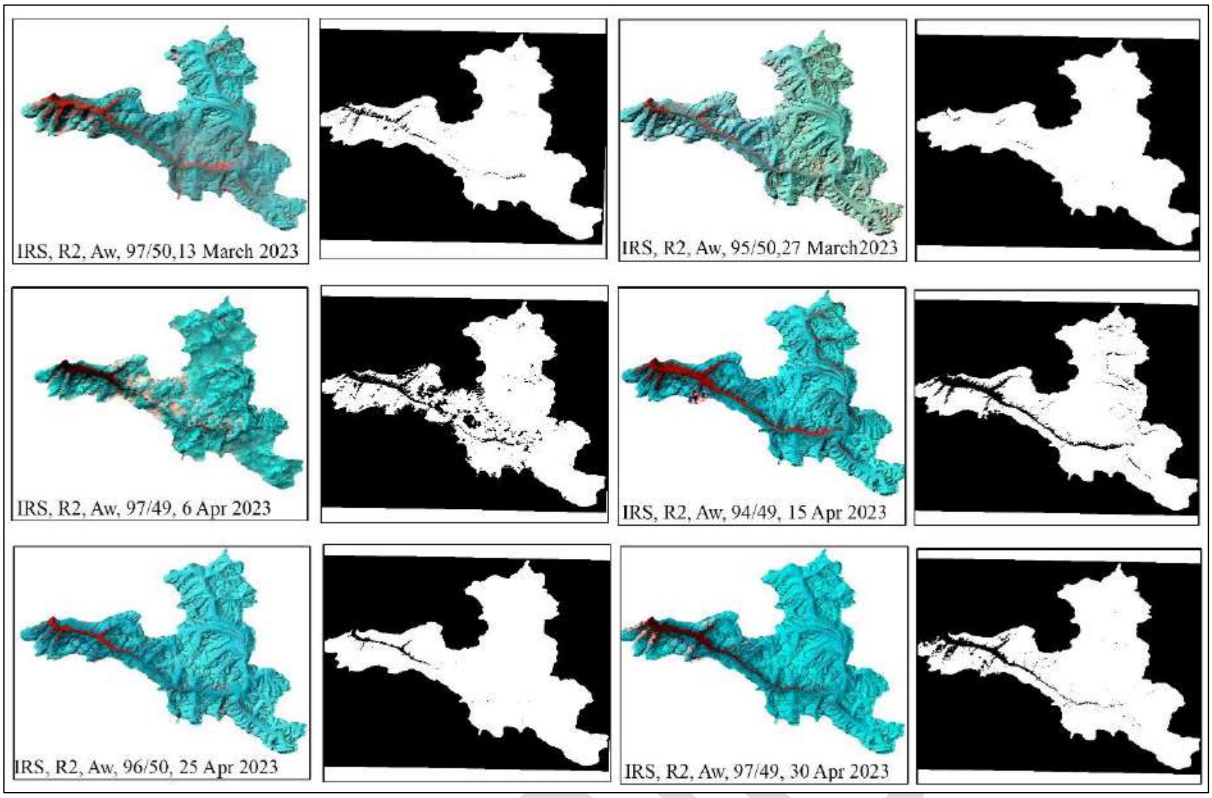
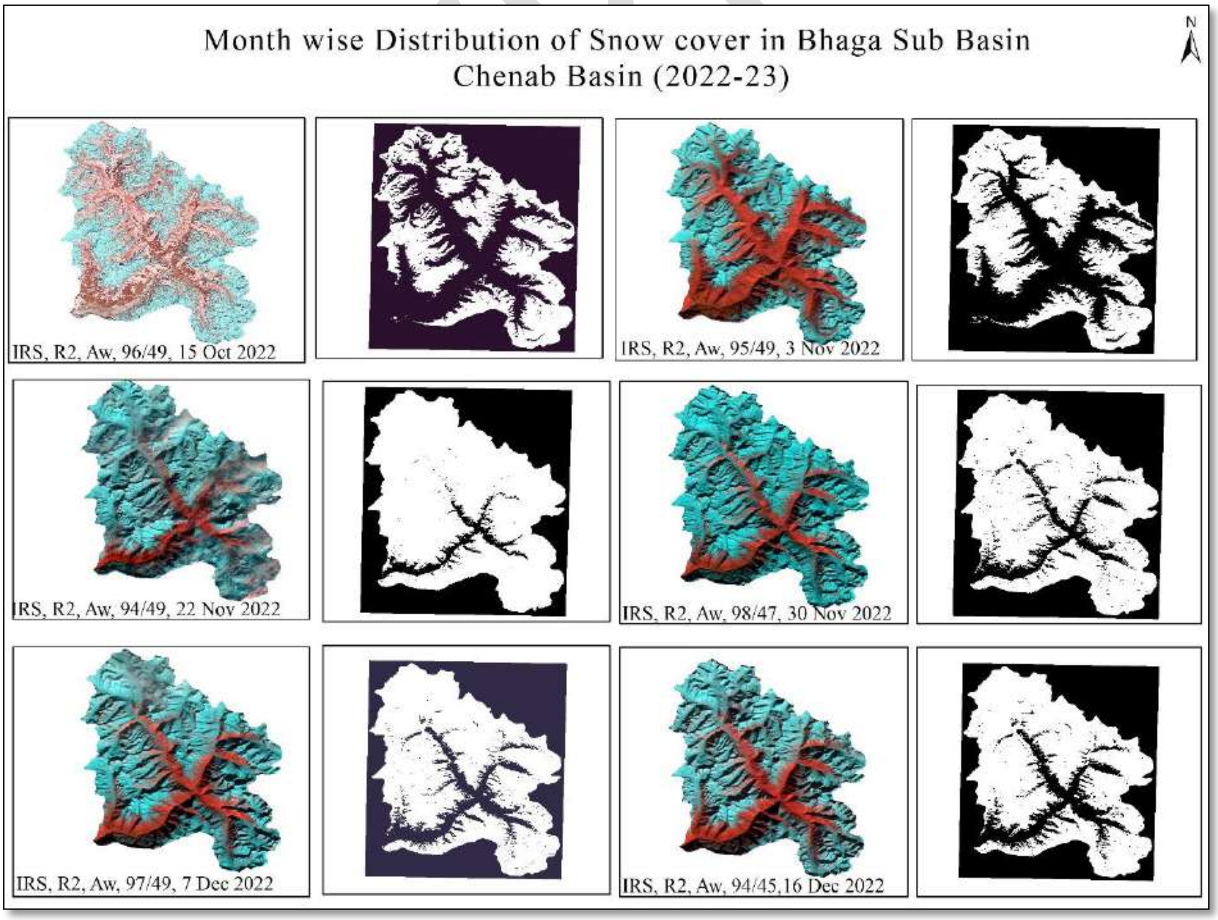


Fig. 2.1.3: Month wise Distribution of Snow cover in Chandra Sub Basin, Chenab Basin



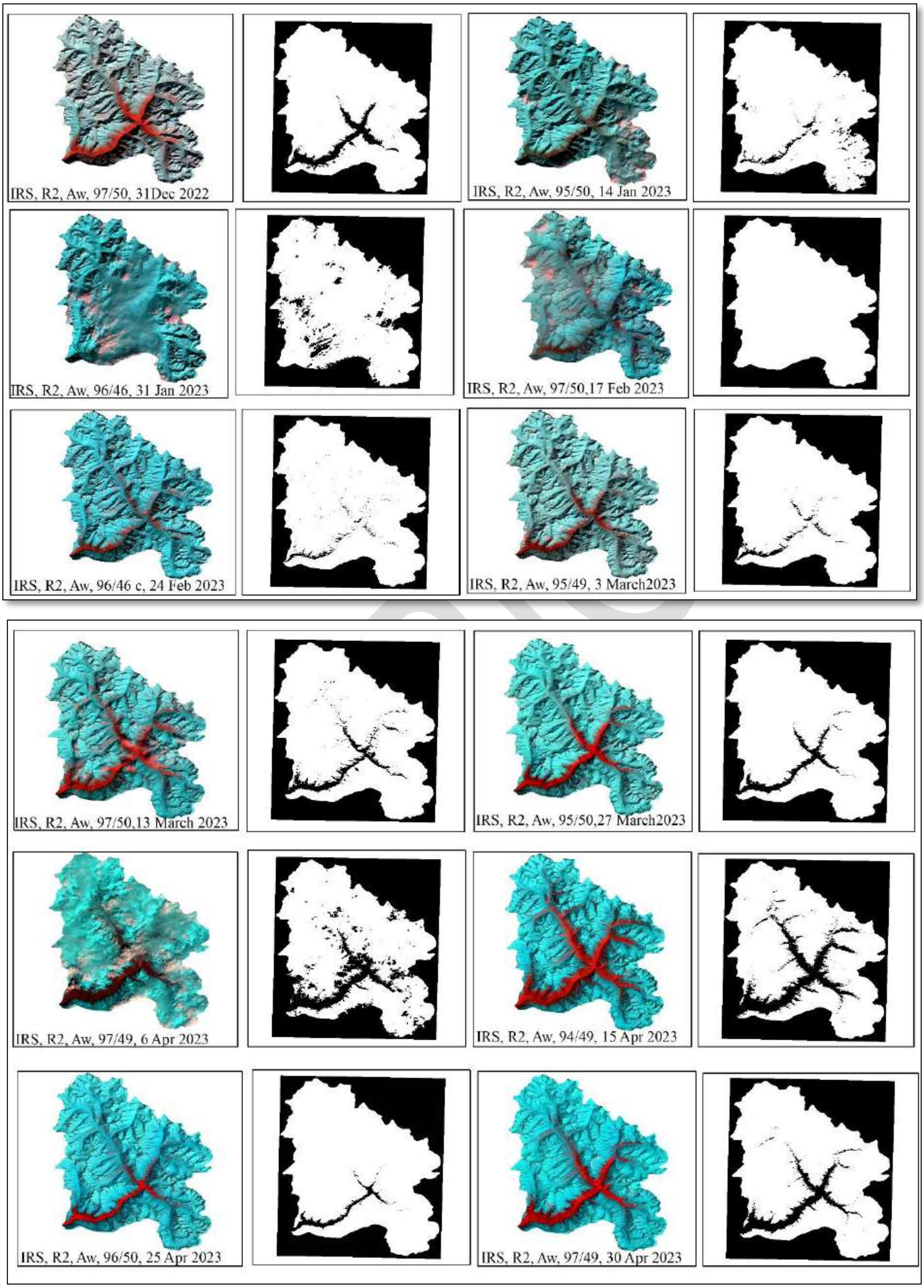
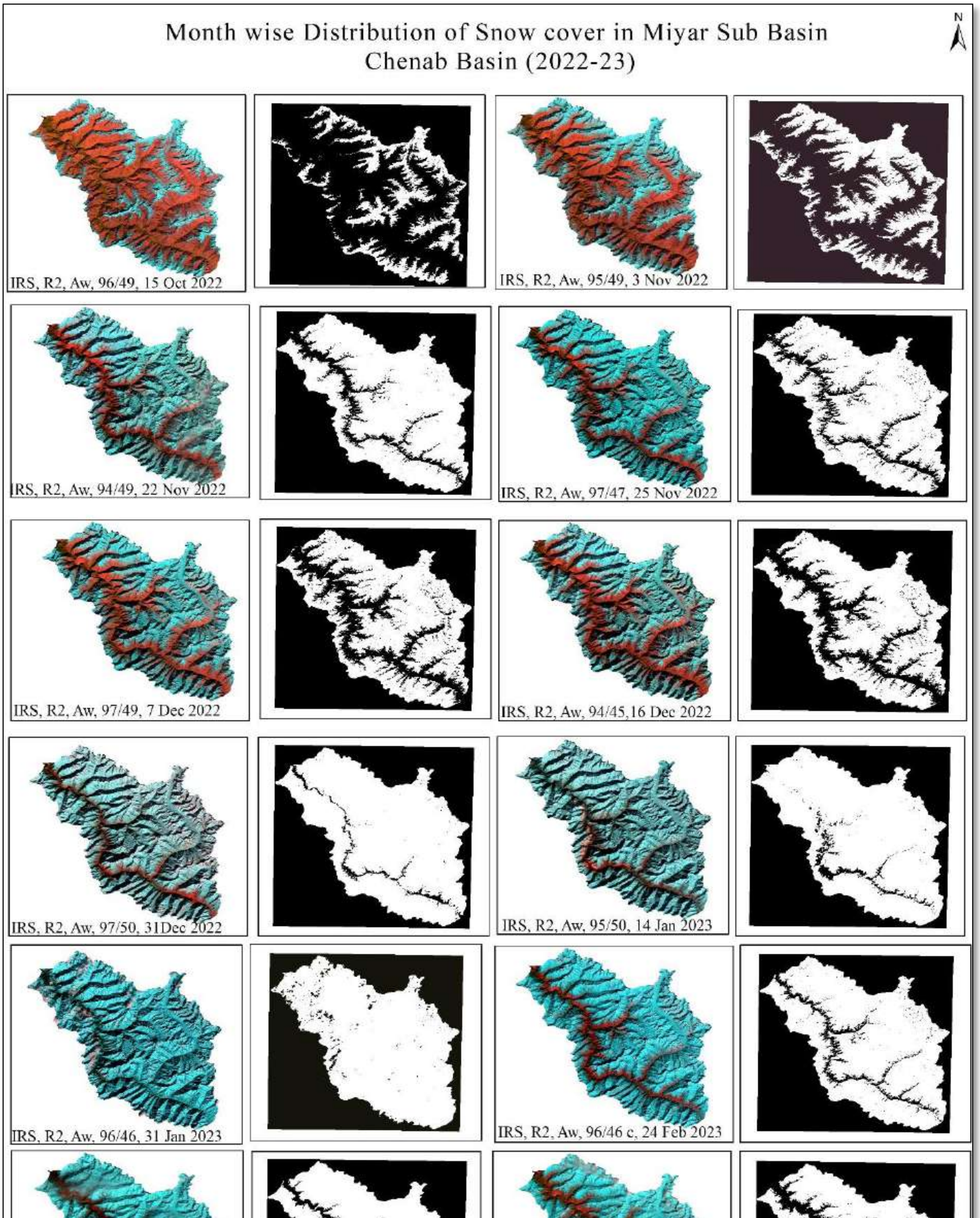


Fig. 2.1.4: Month wise Distribution of Snow cover in Bhaga Sub Basin, Chenab Basin



Month wise Distribution of Snow cover in Miyar Sub Basin
Chenab Basin (2022-23)
N
IRS, R2, Aw, 96/49, 15 Oct 2022
IRS, R2, Aw, 95/49, 3 Nov 2022
IRS, R2, Aw, 94/49, 22 Nov 2022
IRS, R2, Aw, 97/47, 25 Nov 2022
IRS, R2, Aw, 97/49, 7 Dec 2022
IRS, R2, Aw, 94/45,16 Dec 2022
IRS, R2, Aw, 97/50, 31Dec 2022
IRS, R2, Aw, 95/50, 14 Jan 2023
IRS, R2, Aw, 96/46, 31 Jan 2023
IRS, R2, Aw, 96/46 c, 24 Feb 2023
IRS, R2, Aw, 95/49, 3 March2023
IRS, R2, Aw, 97/50,13 March 2023

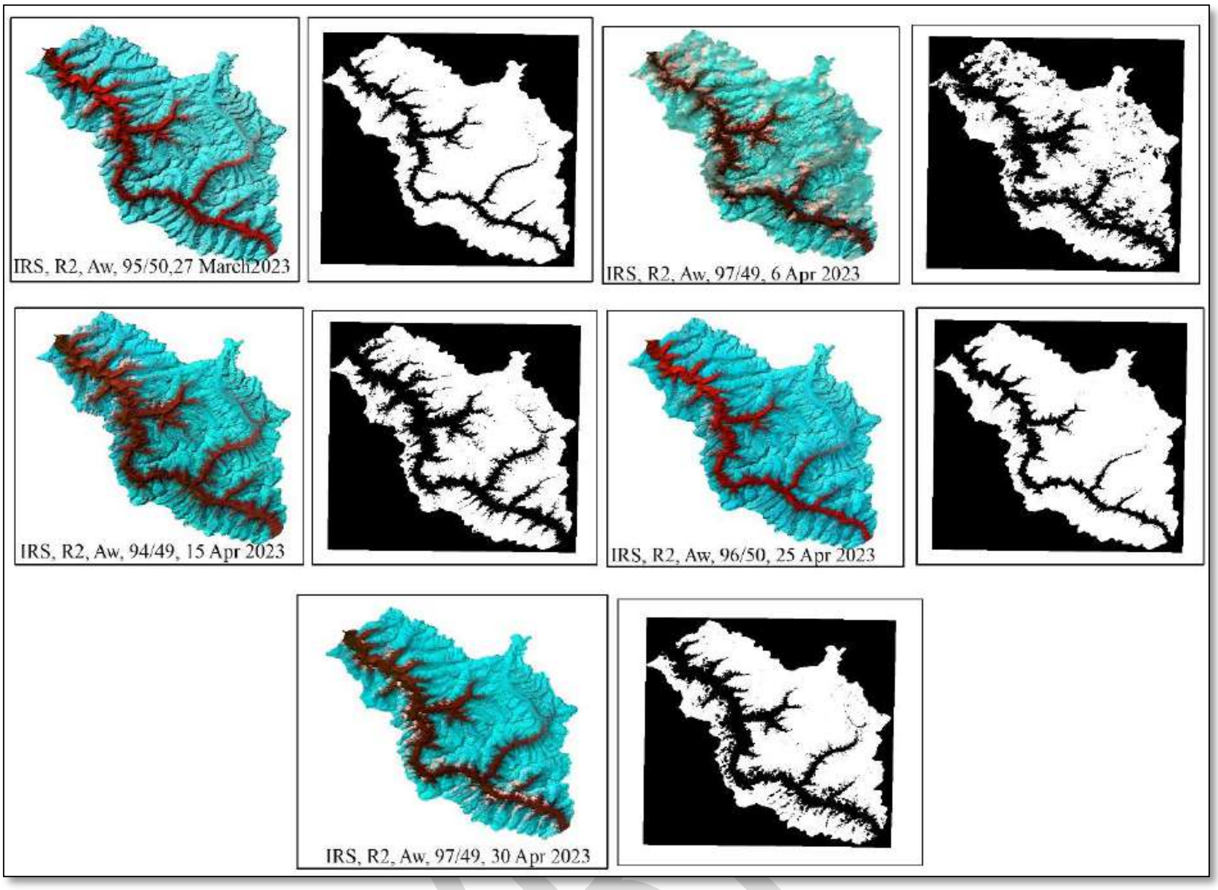


Fig. 2.1.5: Month wise Distribution of Snow cover in Miyar Sub Basin, Chenab Basin

2.2 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 analyzing the satellite data, it is found that in October, the surface area has increased from 1612.30 Km^2 (2021-22) to 1664.64 Km^2 (2022-23) reflecting an overall increase of about 3% in surface area under snow during October 2022-23. Likewise in November, spatial distribution of snow has been increased from 1566.89 Km^2 (2021-22) to 1895.42 Km^2 (2022-23) indicating an increase in area by about 21% in comparison to 2021-22. Further during peak winter period i.e. December to February, in December the Beas basin shows a decrease in the area by about 25% i.e., the surface area has decreased from 2587.75 Km^2 (2021-22) to 1929.44 Km^2 (2022-23). Likewise, the other peak winter months i.e., January and February also show a negative trend in the area under snow in the basin. In January, the surface area has been decreased from 2871.10 Km^2 (2021-22) to 2403.43 (2022-23) and from 3890.21 Km^2 (2021-22) to 2638.74 (2022-23) reflecting a decrease of about 16% and 32% respectively in 2022-23 in comparison to 2021-22. Likewise, during March, a decrease of about 5% was seen in 2022-23 in comparison to 2021-22, wherein, the surface area mapped as 2606.59 Km^2

(2021-22). Reduced to 2464.31 Km^2 (2022-23). At the beginning of ablation season i.e., in April, an increase of about 39% was snow was observed in the Beas basin i.e., surface area under snow of the order of 1605.72 Km^2 (2021-22) has increased to 2226.20 Km^2 (2022-23) in Beas basin reflecting the only month during 2022-23 to have the positive trend in the area under snow. **(Table: 2.2.1 & Fig.: 2.2.1, 2.2.2)**. In general, 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: 2.2.1 & Fig.: 2.1, 2.2)** with an overall reduction of 9% surface area from October April in the basin during 2022-23

Table 2.2.1: 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**

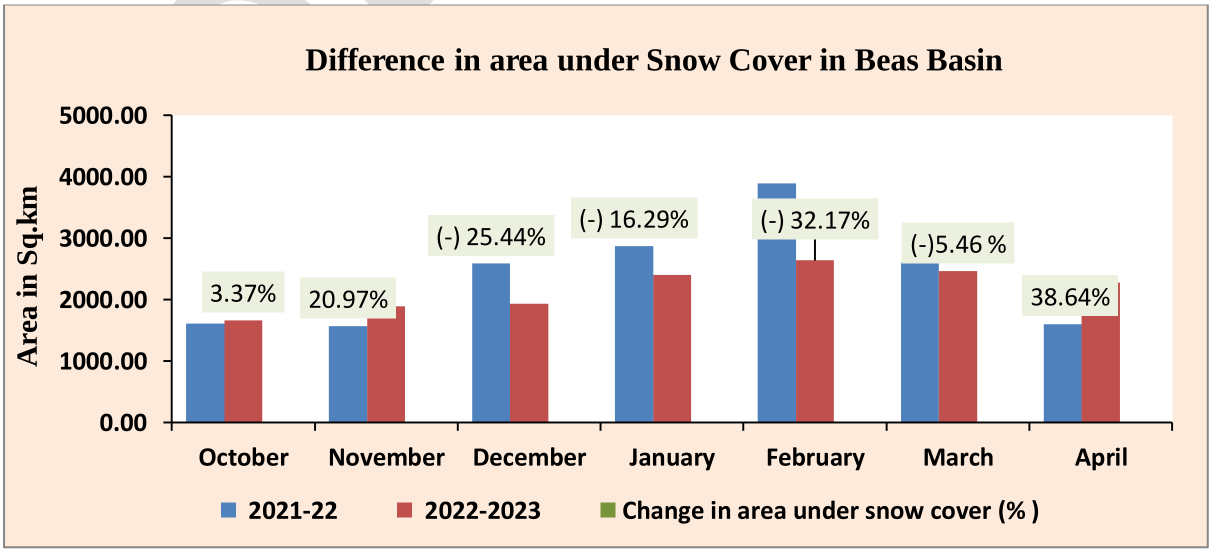


Fig. 2.2.1: Difference in Area under Snow cover in Beas Basin

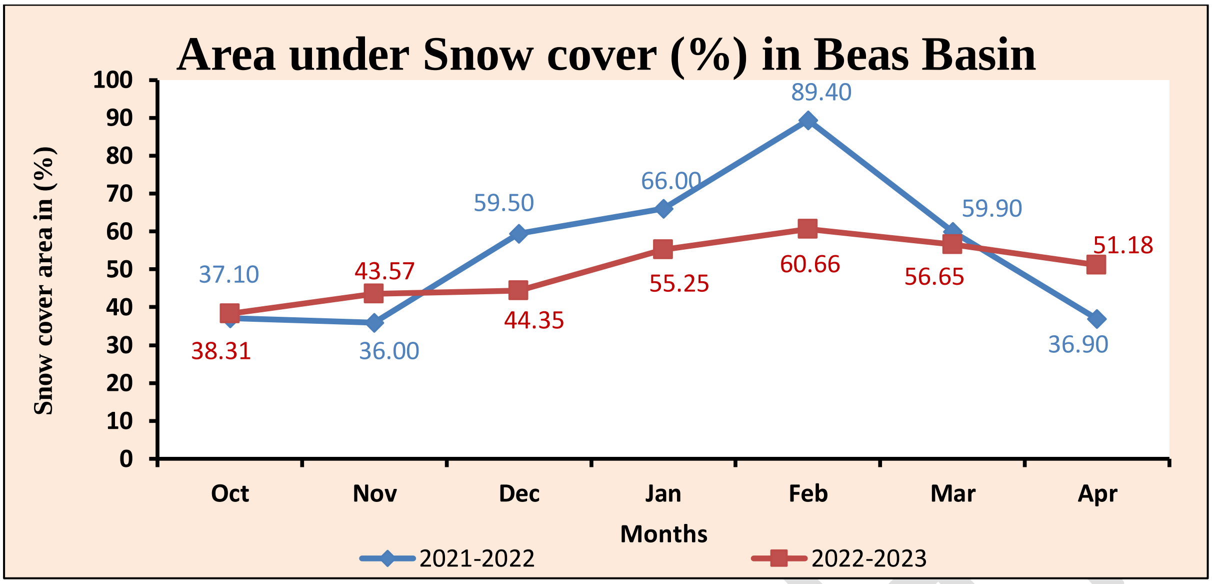
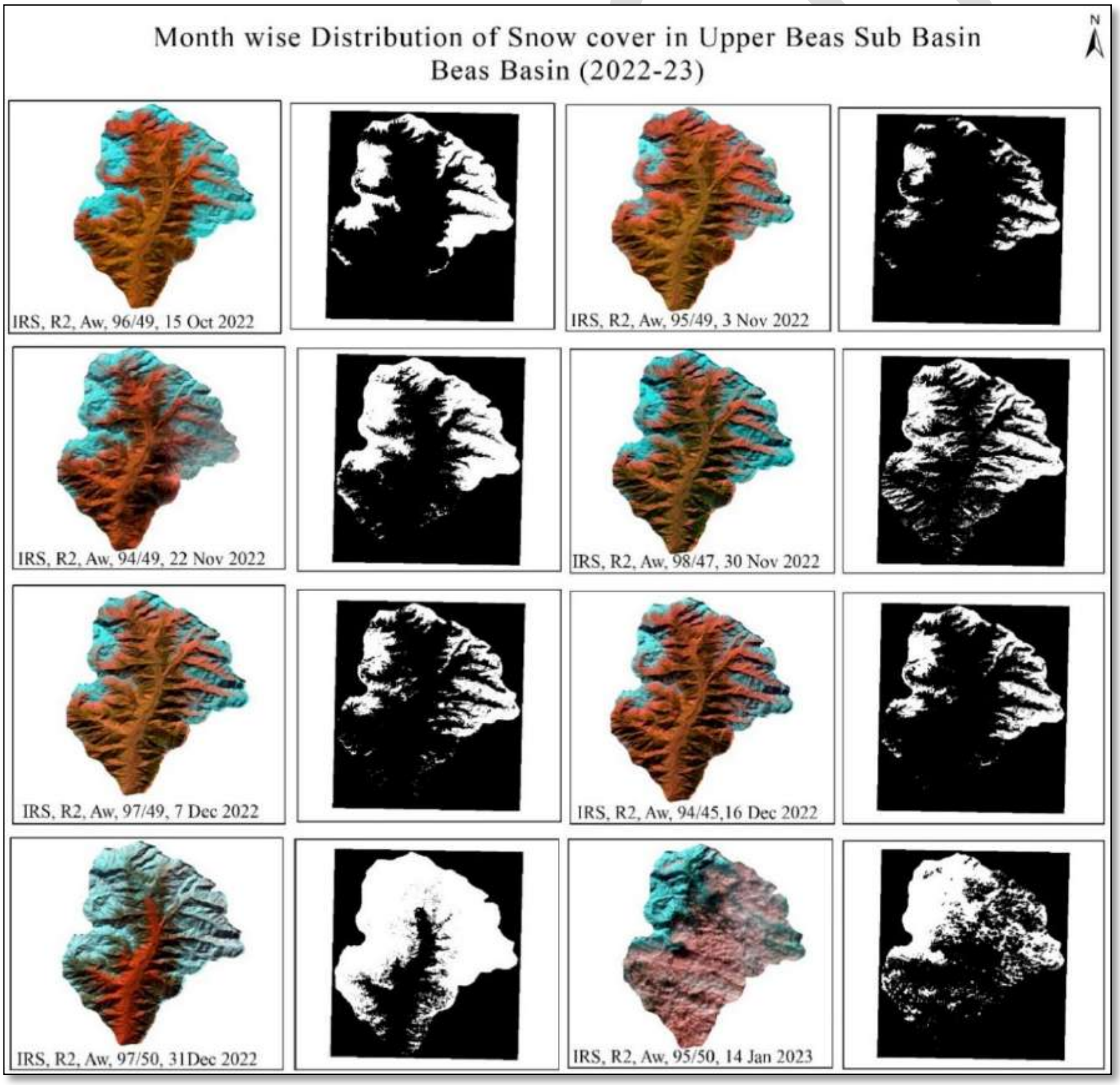


Fig. 2.2.2: Area under Snow cover (%) in Beas Basin



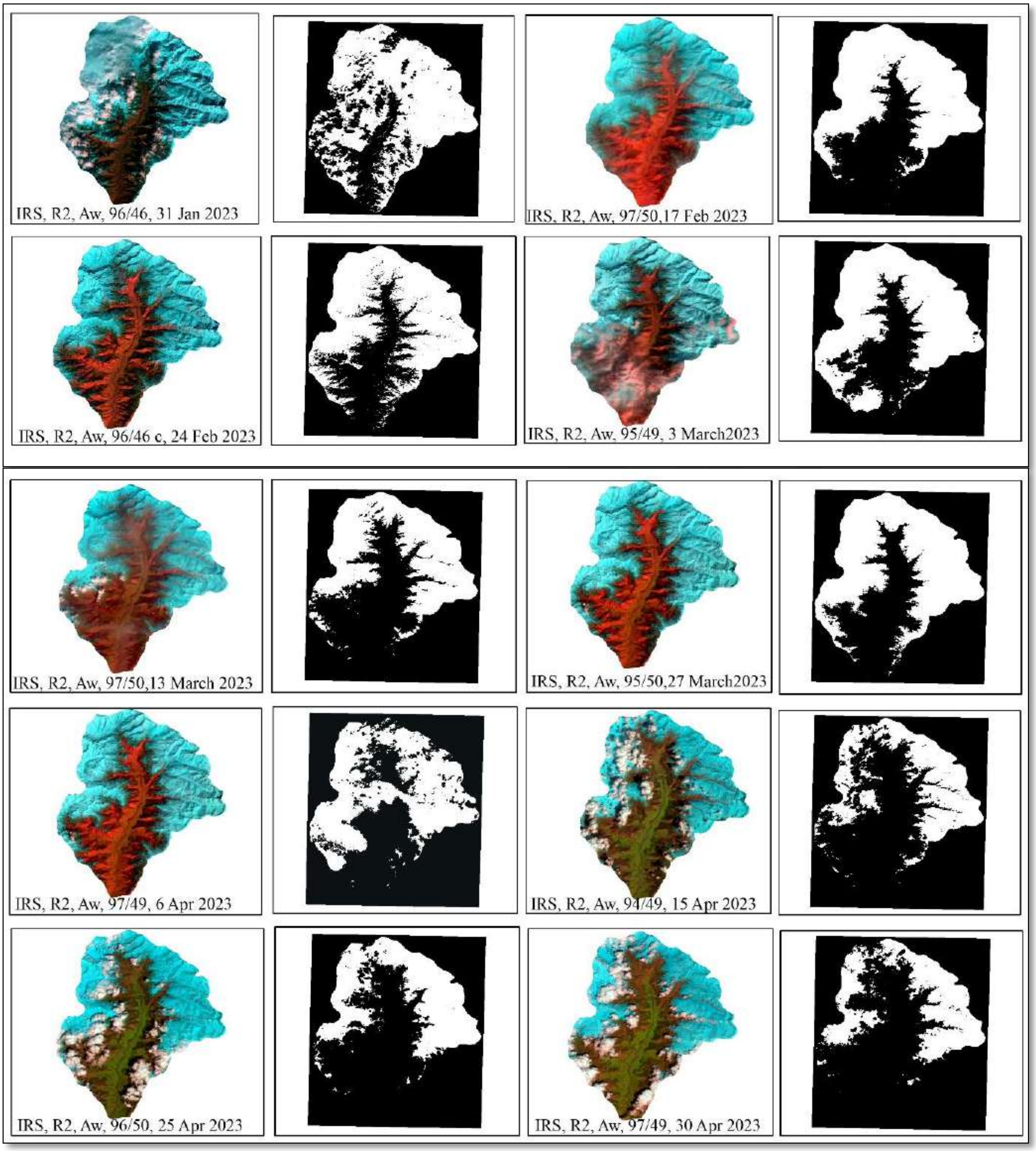
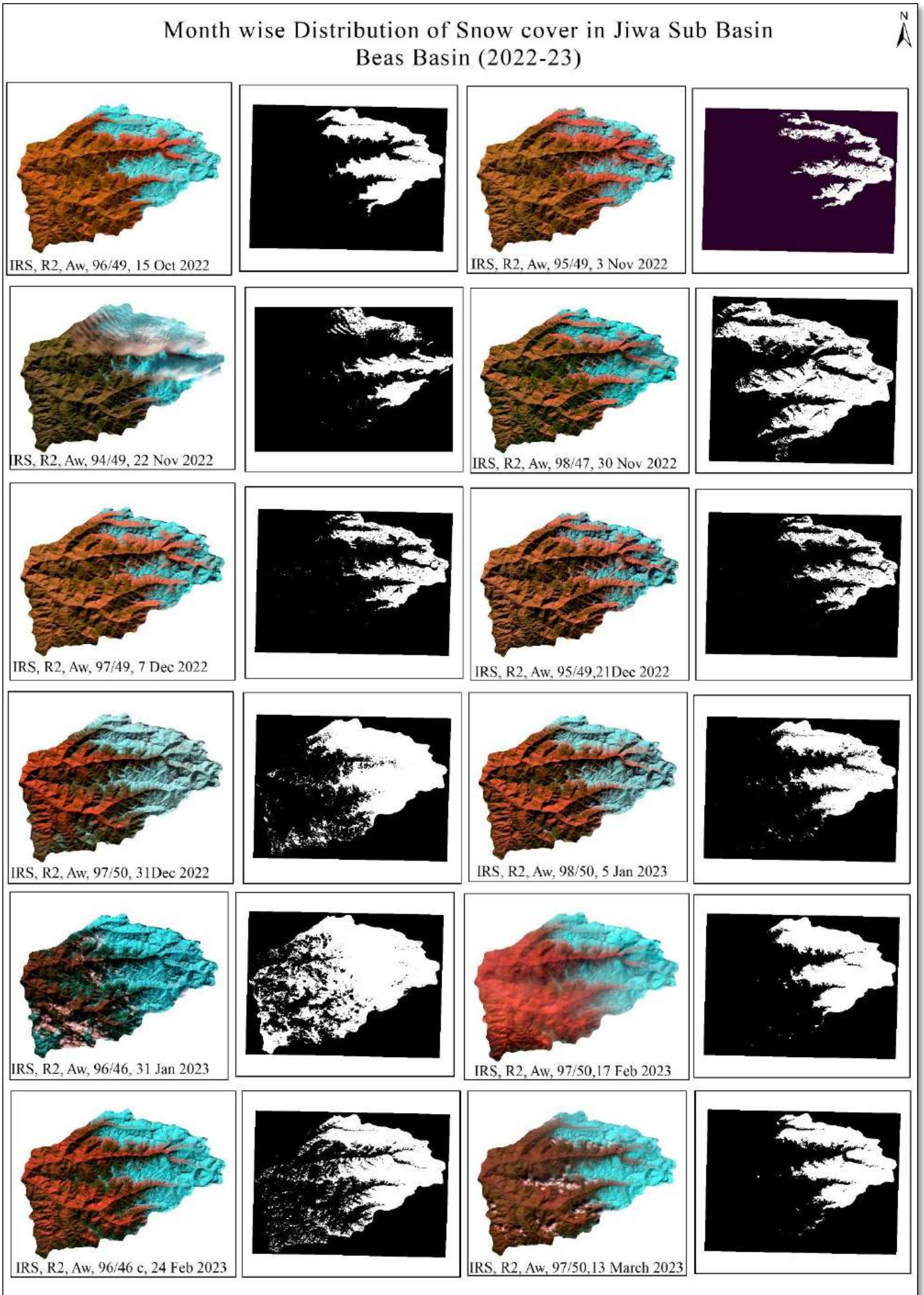


Fig. 2.2.3: Month wise Distribution of Snow cover in Beas Sub Basin, Beas Basin

Month wise Distribution of Snow cover in Jiwa Sub Basin
Beas Basin (2022-23)



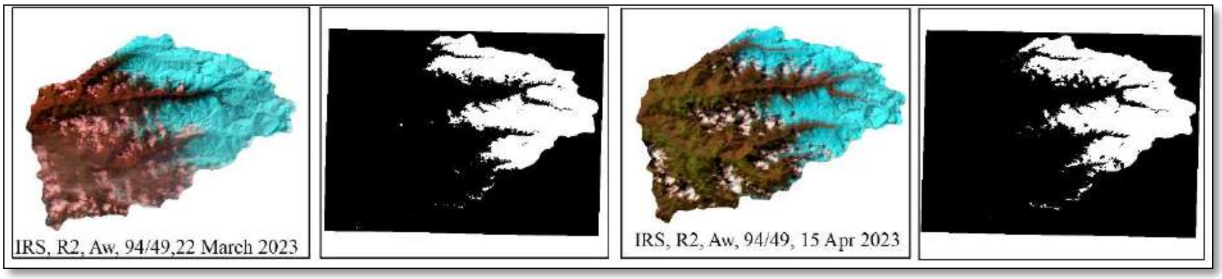
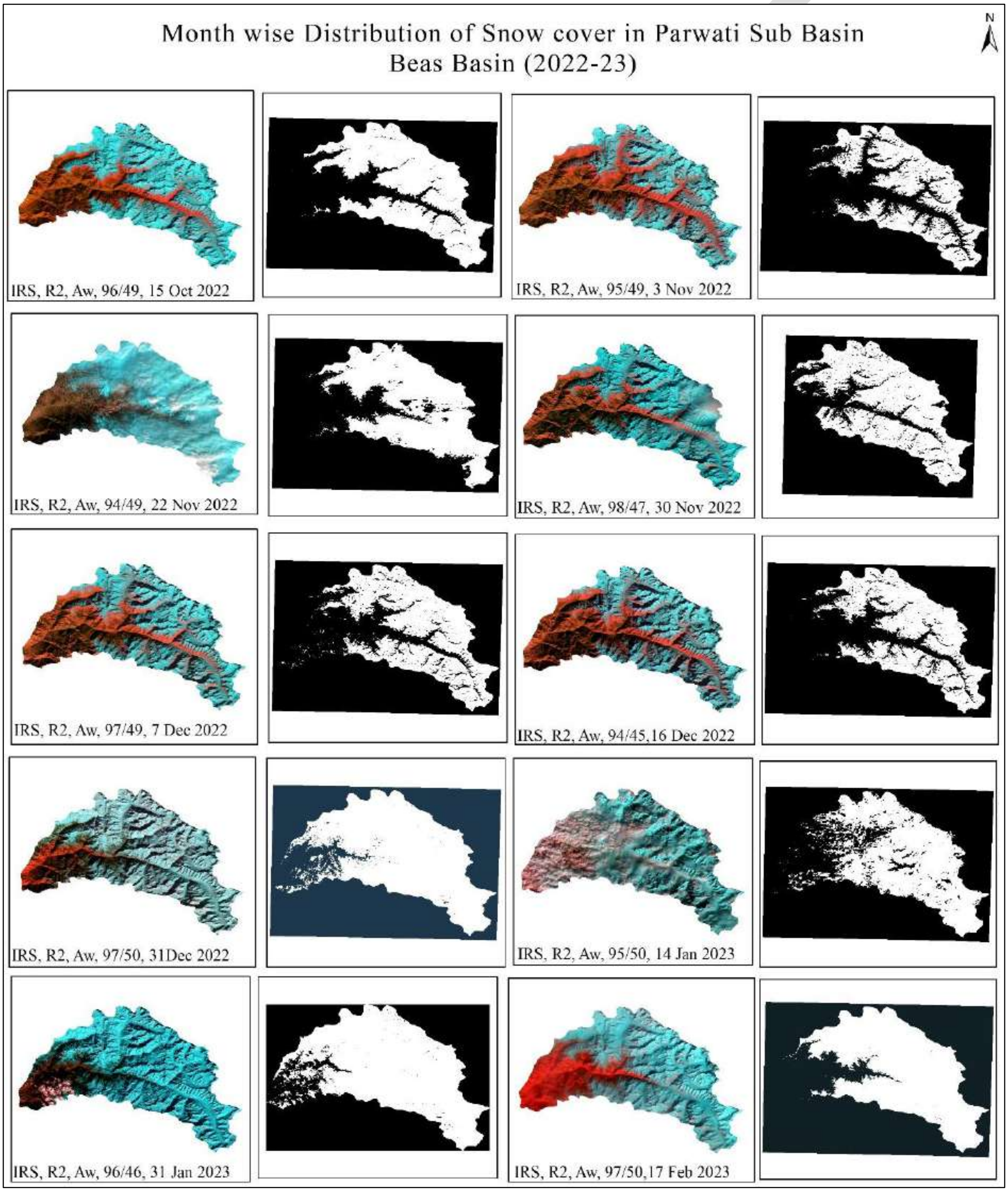


Fig. 2.2.4: Month wise Distribution of Snow cover in Jiwa Sub Basin, Beas Basin



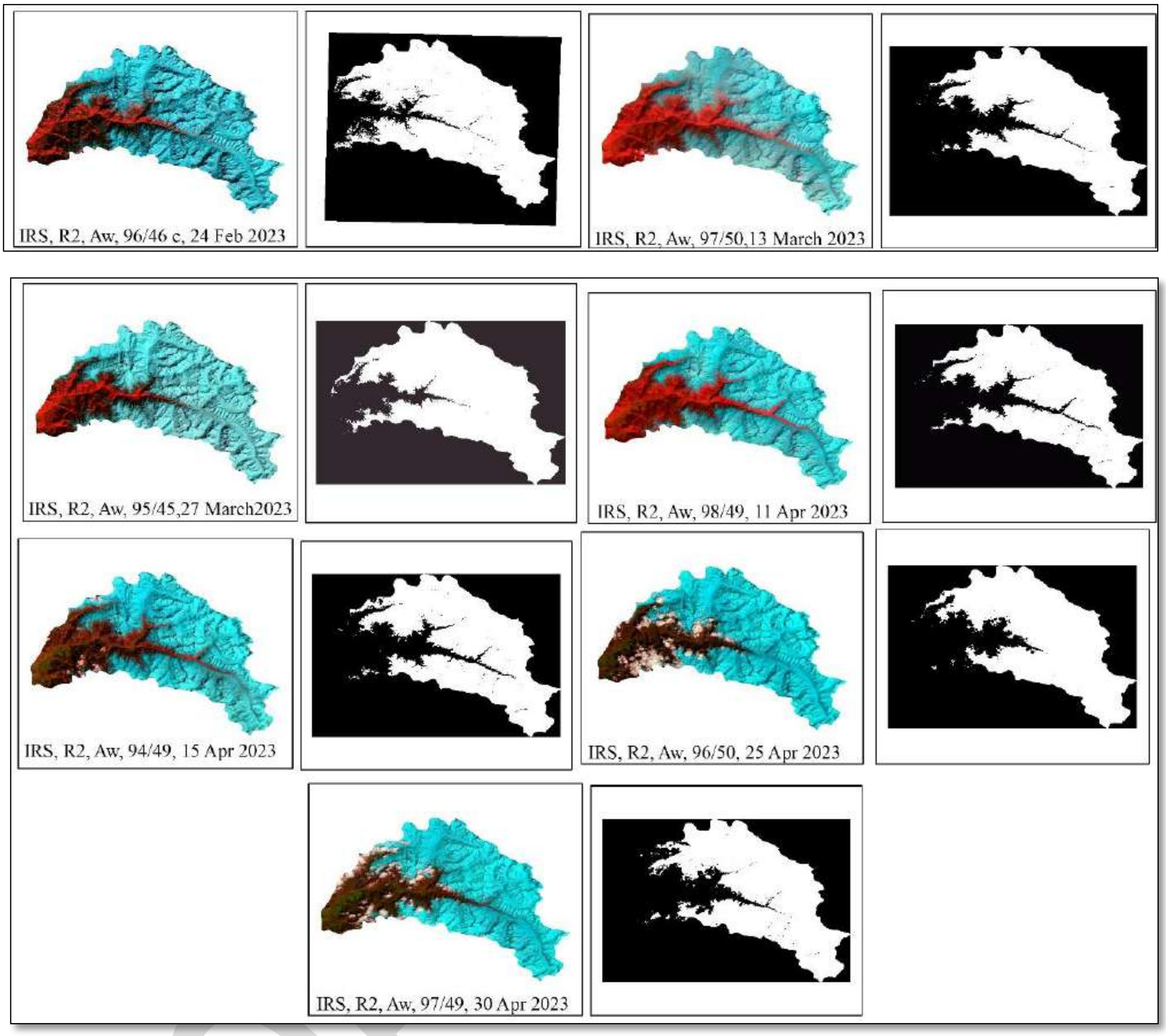


Fig. 2.2.5: Month wise Distribution of Snow cover in Parvati Sub Basin, Beas Basin

2.3 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 analyzing the satellite data, it is found that in October, the surface area has decreased from 2167.18 Km^2 in 2021-22 to 997.65 Km^2 (2022-23) reflecting a very sharp decrease of snow cover area by about 54% between 2021-22 and 2022-23 winters. Likewise, in November, spatial distribution of snow has also decreased from 1651.91 Km^2 (2021-22) to 1592.87 Km^2 (2022-23) reflecting an overall reduction of about 4% in 2022-23 in comparison to 2021-22. Further in December, a decrease of about 12% in terms of the total surface area under snow was observed in

2022-23 in comparison to 2021-22 i.e., the surface area has reduced to 1772.36 Km^2 (2022-23) from 2010.05 Km^2 (2021-22). In January, also the total area has reduced from 2967.58 Km^2 (2021-22) to 2865.29 Km^2 (2022-23) indicating an overall decrease of about 3% in the Ravi basin. Likewise, further in February a decrease of about 12% was seen in 2022-23 in comparison to 2021-22 i.e., the surface area has decreased from 2605.60 Km^2 (2021-22) to 2295.91 Km^2 (2022-23), whereas March also shows a negative trend with reduction in the surface area by about 7% i.e., the area under snow has further reduced from 2213.98 Km^2 in 2021-22 to 2053.53 Km^2 in 2022-23. During the beginning of ablation period in April i.e., the Ravi basin also shows a similar trend like that of other adjoining basins i.e., the surface area increased from 1059.06 Km^2 (2021-22) to 1626.46 Km^2 (2022-23) reflecting an increase of about 54% during April (2022-23) in comparison to (2021-22) (Table-2.3.1 & Figure-2.3.1, 2.3.2). In general, 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-2.3.1 & Figure-2.3.1, 2.3.2).

Table 2.3.1: 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**	**1886.29**	**38.44**	**-10.02**

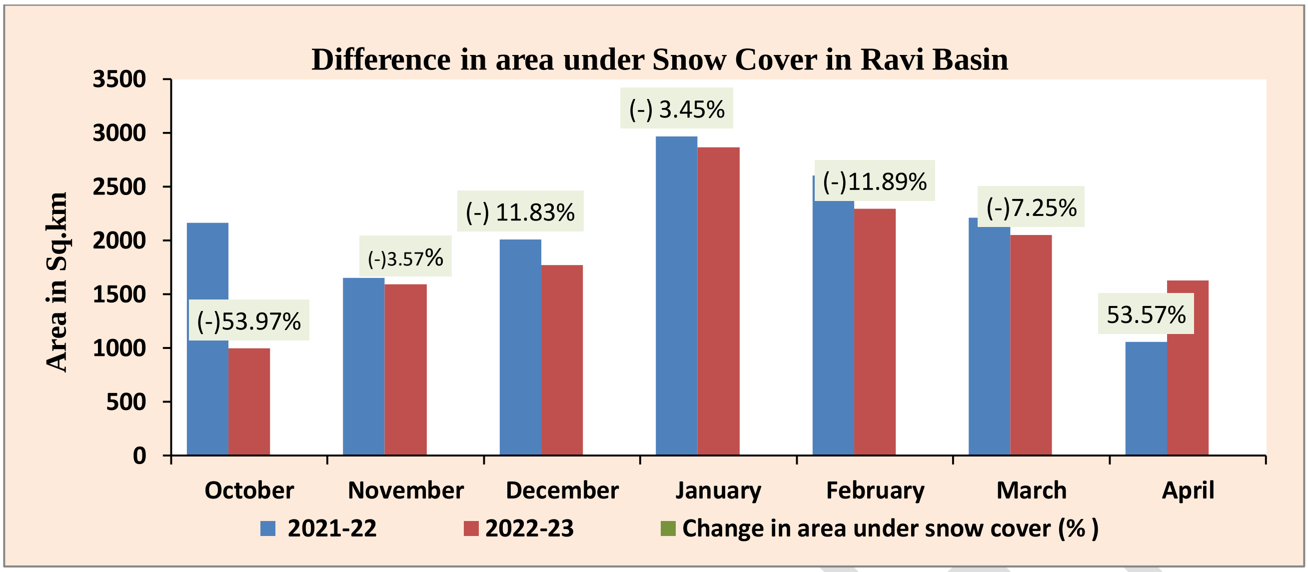


Fig. 2.3.1: Difference in Area under Snow Cover (%) in Ravi Basin

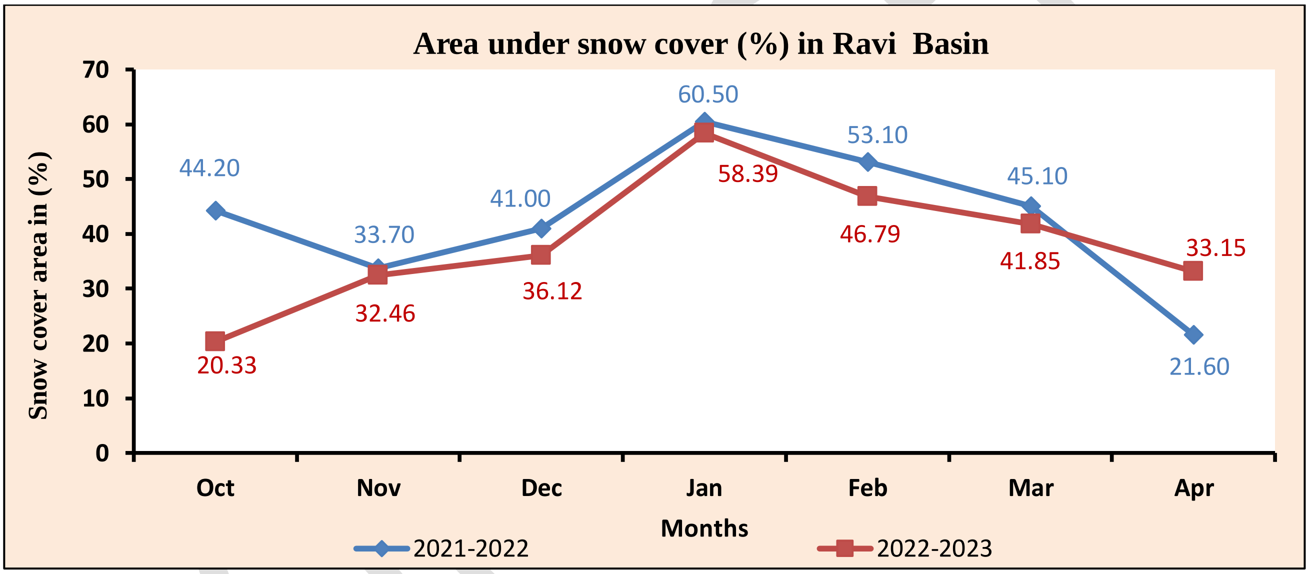
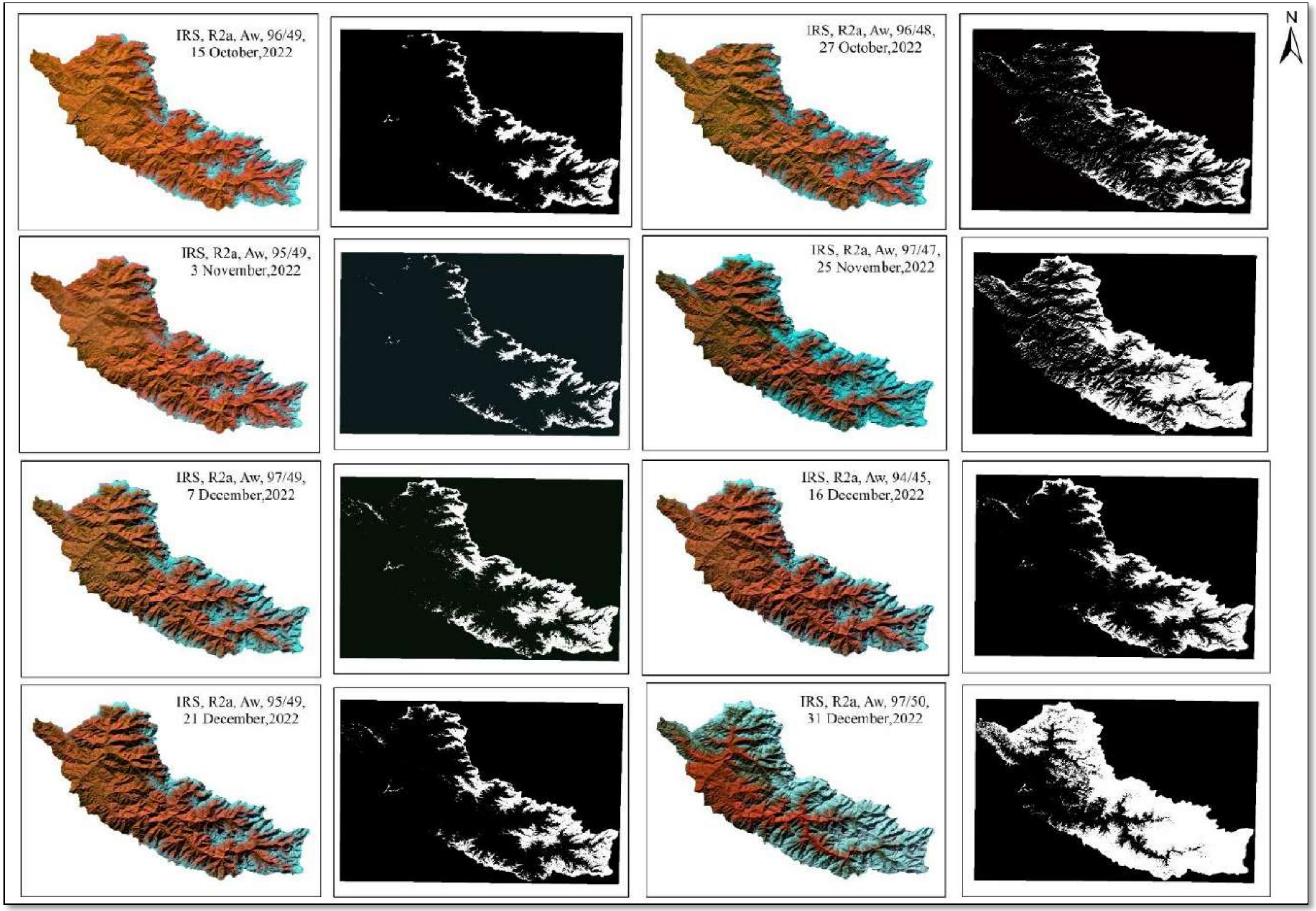


Fig. 2.3.2: Area under Snow Cover (%) in Ravi Basin

Month-Wise Distribution of Snow Cover in Ravi Basin (2022-23)



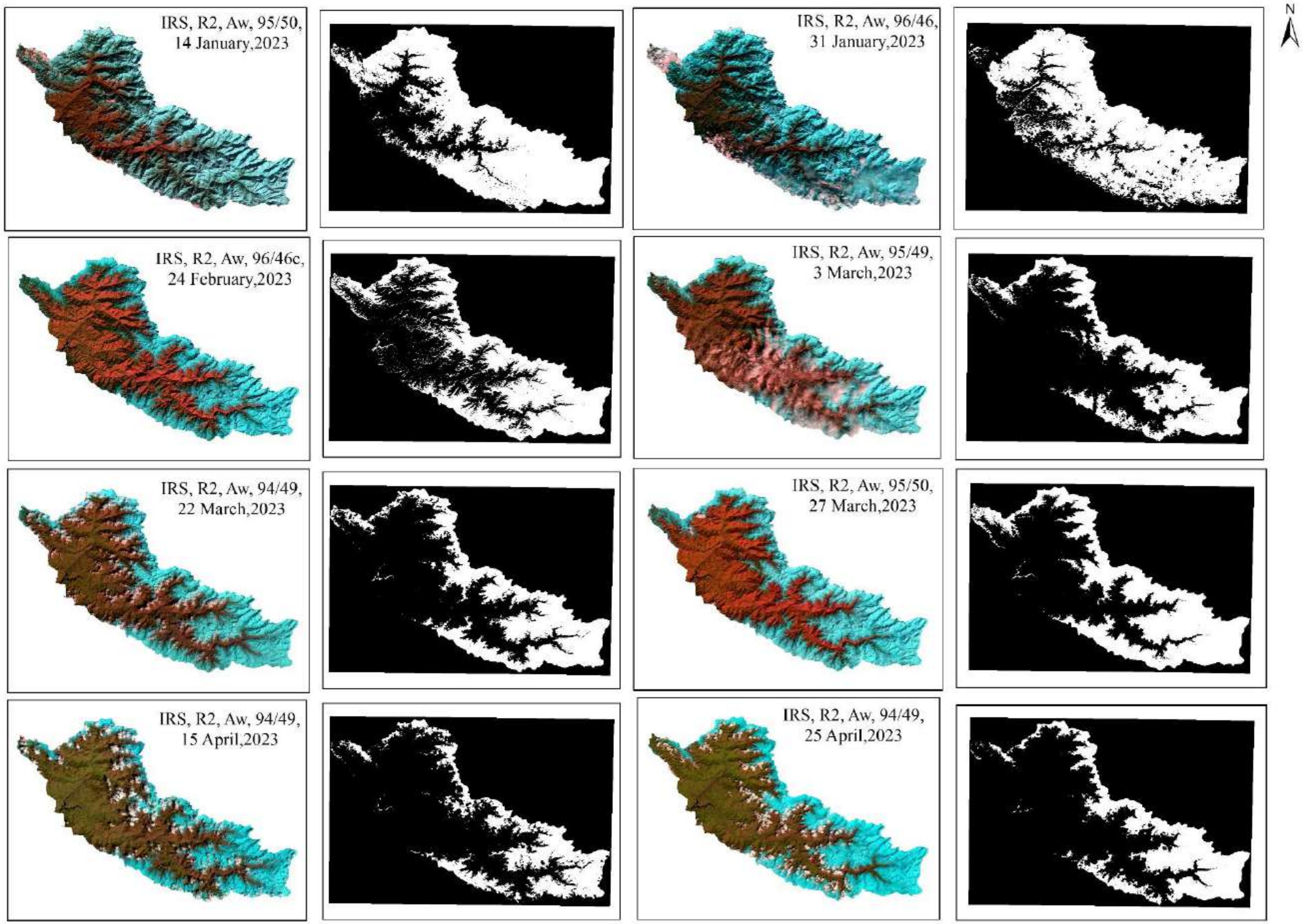


Fig. 2.3.3: Month-Wise Distribution of Snow Cover in Ravi Basin (2022-23)

2.3 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 for the month of October 2022-23, it is found out that the total area under snow has been reduced by about 27% in 2022-23 i.e., the area under snow in 2022-23 in the month of Oct was mapped as 6926.18 Km^2 in 2021-22 reduced to 5067.66 Km^2 in 2022-23. Likewise, in November 2022-23, the snow cover area has decreased by about 22% in comparison to 2021-22, wherein the surface area has reduced from 10001.18 Km^2 in 2021 22 to 5435.58 Km^2 in 2022-23. In December similar trend was also observed reflecting an overall reduction by about 56% i.e., the surface area under snow has reduced from 12304.65 Km^2 (2021-22) to 5435.80 Km^2 (2022-23) respectively. Likewise, in January & February, a reduction of about 38% and 17% was seen based on the analysis of 2022-23 satellite data in comparison to 2021-22 reflecting that the snow cover has reduced from 15211.40 Km^2 (2021-22) to 9445.43 Km^2 (2022-23 in the month of January and from 15922.90 Km^2 (2021-22) to 13172.24 Km^2 (2022-23) in February respectively. Likewise, March also shows a marginal reduction in snow cover area by about 4% in 2022-23 in comparison to 2021-22 reflecting that the surface area has reduced from 11869.10 Km^2 (2021-22) to 11445.42 Km^2 (2022-23). During summer months, in April, the total area under snow is 9733.77 Km^2 (2022-23) in comparison to 7526.28 Km^2 (2021-22) indicating an enhancement of about 29% at the beginning of the summer ablation period. In general, 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: 2.4.1 & Fig.: 2.4.1, 2.4.2).**

Table 2.4.1: 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**	**8868.27**	39.13	**-22.20**

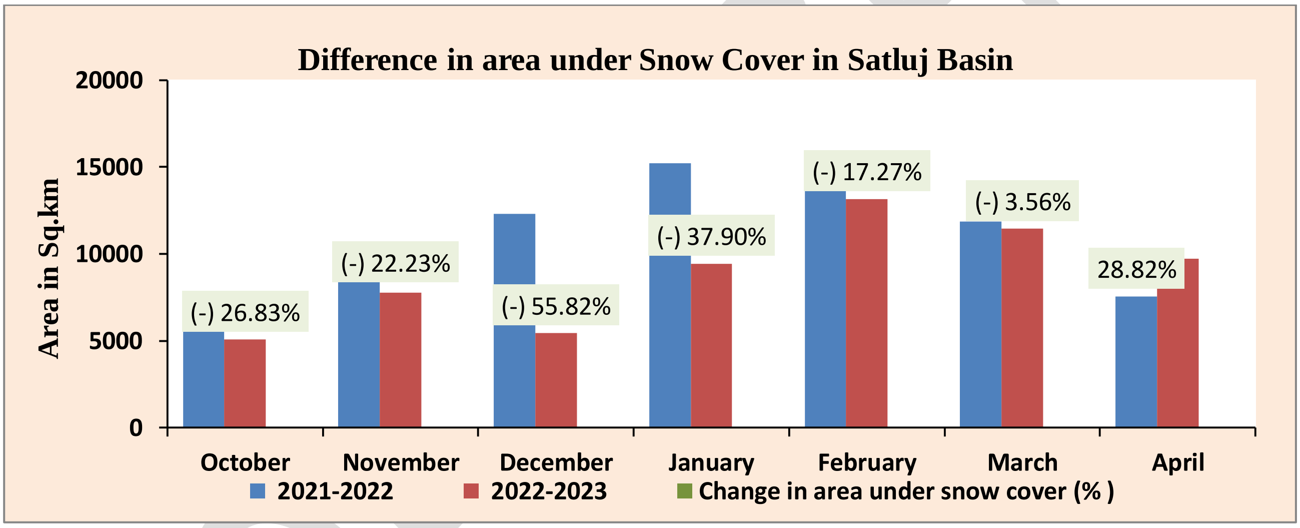


Fig. 2.4.1: Difference in Area under Snow Cover in Satluj Basin

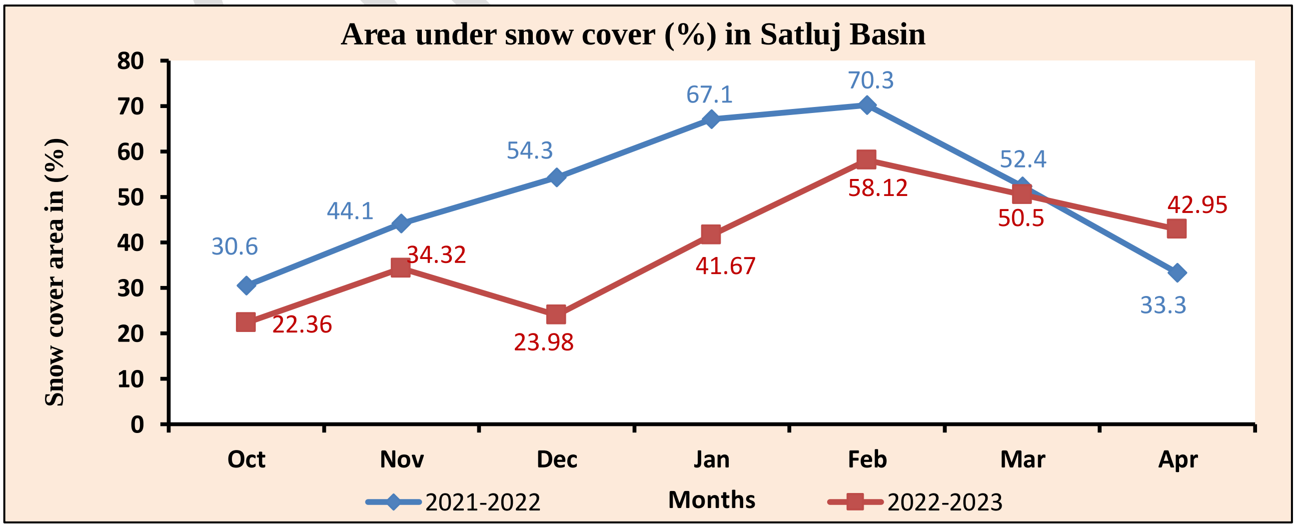
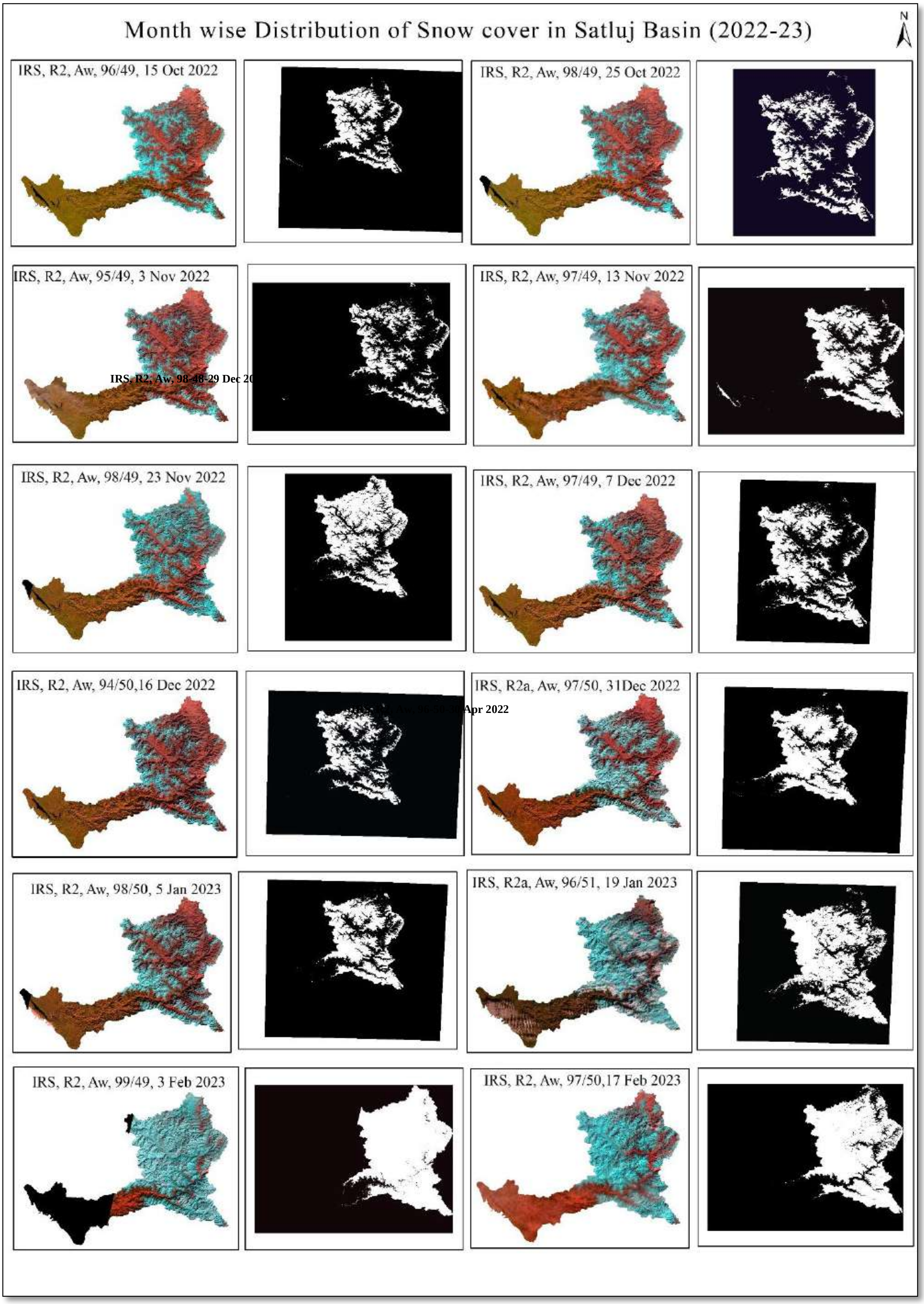


Fig. 2.4.2: Area under Snow Cover (%) in Satluj Basin


Month wise Distribution of Snow cover in Satluj Basin (2022-23)
N
IRS, R2, Aw, 96/49, 15 Oct 2022
IRS, R2, Aw, 98/49, 25 Oct 2022
IRS, R2, Aw, 95/49, 3 Nov 2022
IRS, R2, Aw, 97/49, 13 Nov 2022
IRS, R2, Aw, 98/49, 23 Nov 2022
IRS, R2, Aw, 97/49, 7 Dec 2022
IRS, R2, Aw, 94/50,16 Dec 2022
IRS, R2a, Aw, 97/50, 31Dec 2022
IRS, R2, Aw, 98/50, 5 Jan 2023
IRS, R2a, Aw, 96/51, 19 Jan 2023
IRS, R2, Aw, 99/49, 3 Feb 2023
IRS, R2, Aw, 97/50,17 Feb 2023

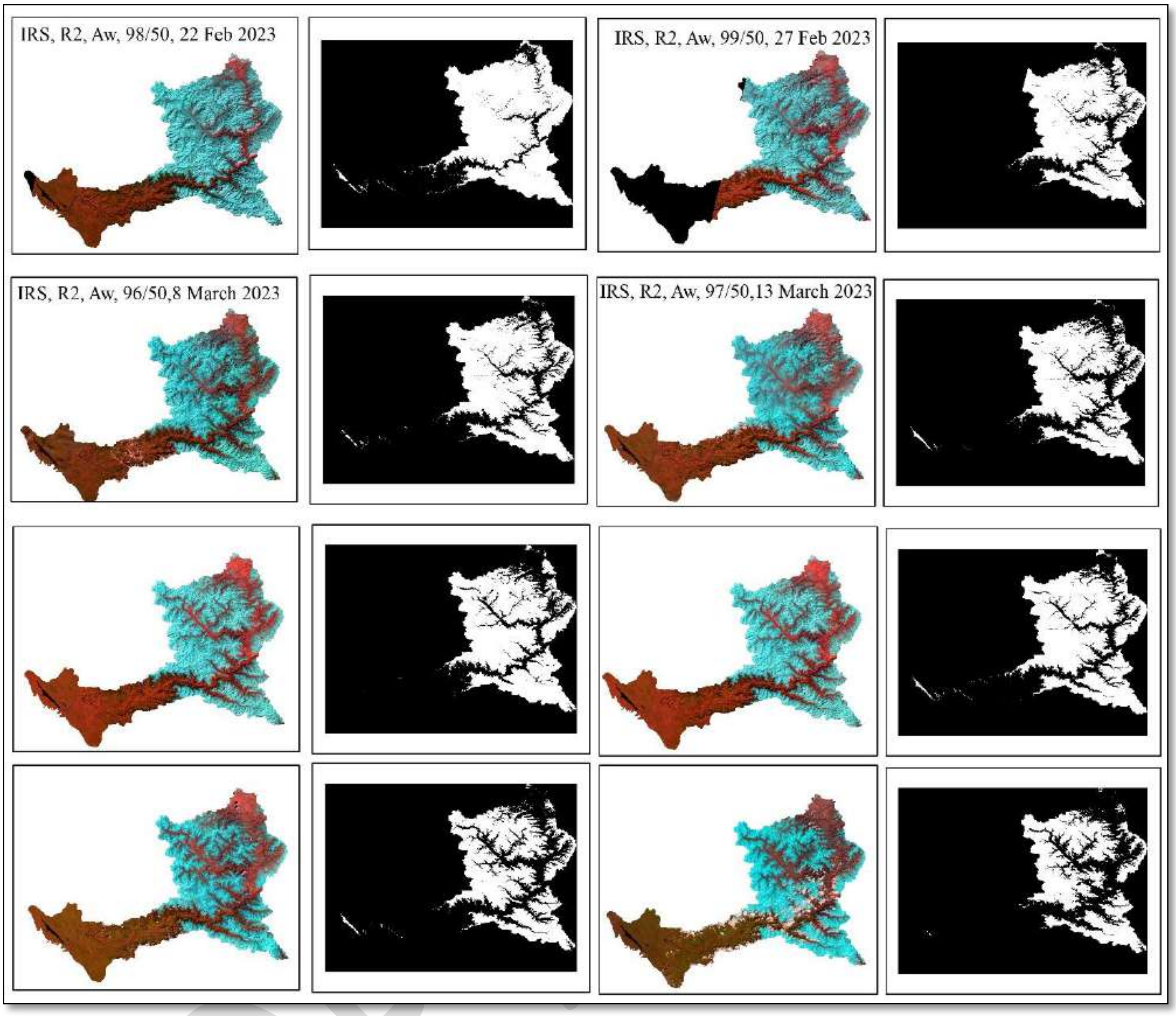


Fig. 2.4.3: Month-Wise Distribution of Snow Cover in Satluj Basin (2022-23)

3. Basin Wise Comparative Analysis of Area under Snow Cover

Table 3.1: - 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

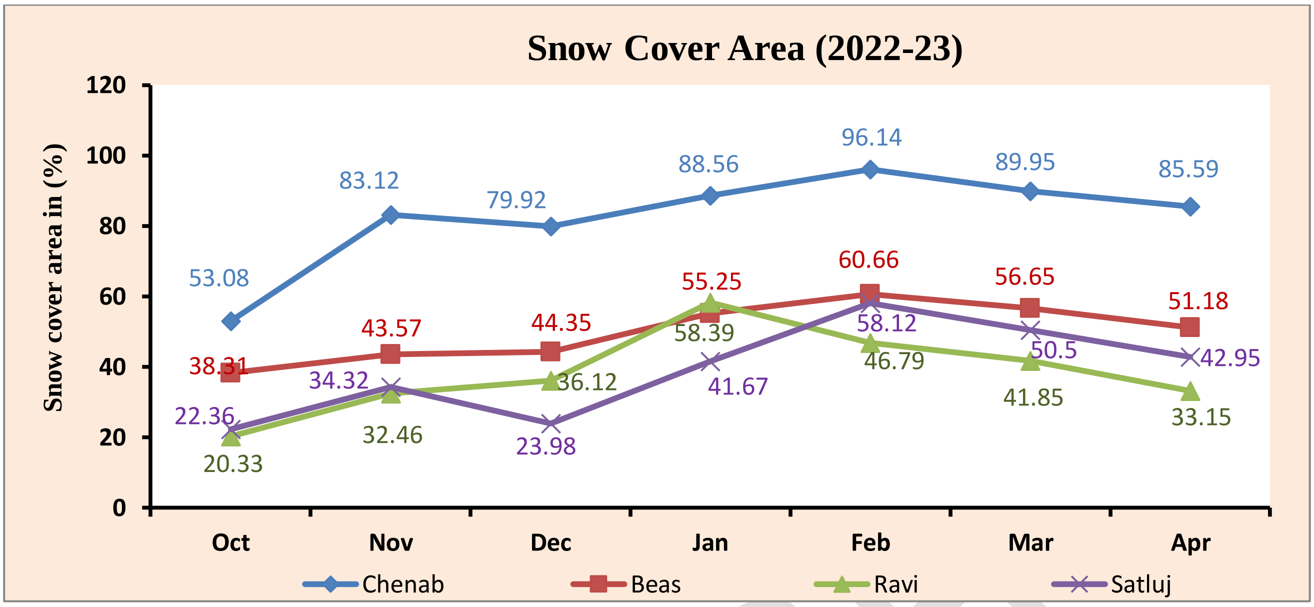


Fig. 3.1: Basin Wise Area under Snow Cover (%) in Himachal Pradesh (2022-23)

Table 3.2: Area under Snow in Himachal Pradesh

Basin-wise Snow Cover in H.P (Km²)			
Basin	**2021-2022**	**2022-2023**	**Difference in area (%)**
Chenab	**7357.22**	**7049.67**	(-)4.18
Beas	**2391.49**	**2174.88**	(-)9.06
Ravi	**2096.48**	1886.29	(-)10.02
Satluj	**11398.81**	**8868.27**	(-)22.20
Total	**23244**	19979.11	(-)14.05

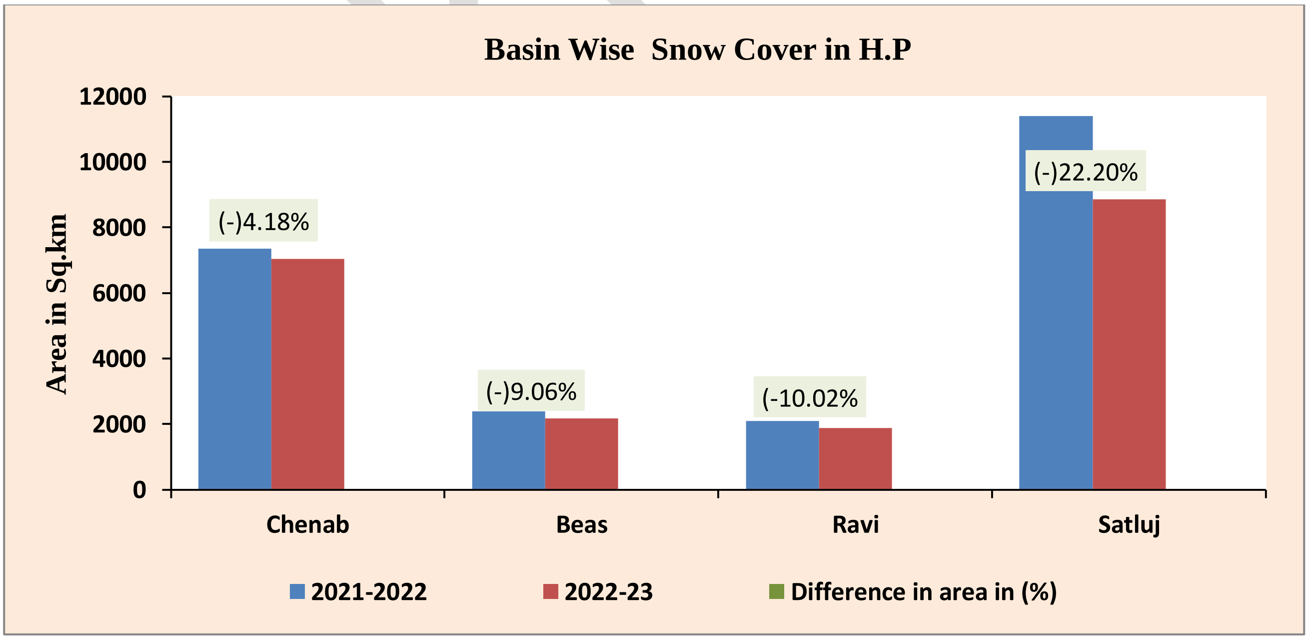


Fig. 3.2: Basin Wise Snow Cover in H.P

Thus, based on the above analysis, it is observed that during 2022-23, there was an overall reduction of about 14.05 % in total area under snow cover in Himachal Himalaya (**Fig. 3.3 and Table 3.3).** The analysis of Figure 3.3, reveals that all the four major rivers basins of the state i.e., Chenab, Beas, Ravi and Satluj shows decrease in the snow cover area in 2022-23 in comparison to 2021-22. The dominant reduction in terms of the total monthly average area (Oct to April) observed in case of Satluj (22.20%), Ravi (10.02%), Beas (9.06%) and Chenab (4.18%) in 2022-23 in comparison to 2021-22 (**Fig. 3.2 & Table-3.2**).

Table 3.3: Total Area under snow in H.P

Year	2021-22 Area in km^2	2022-2023 Area in km^2	% change
Total Area	**23244**	19979.11	(-)14.05

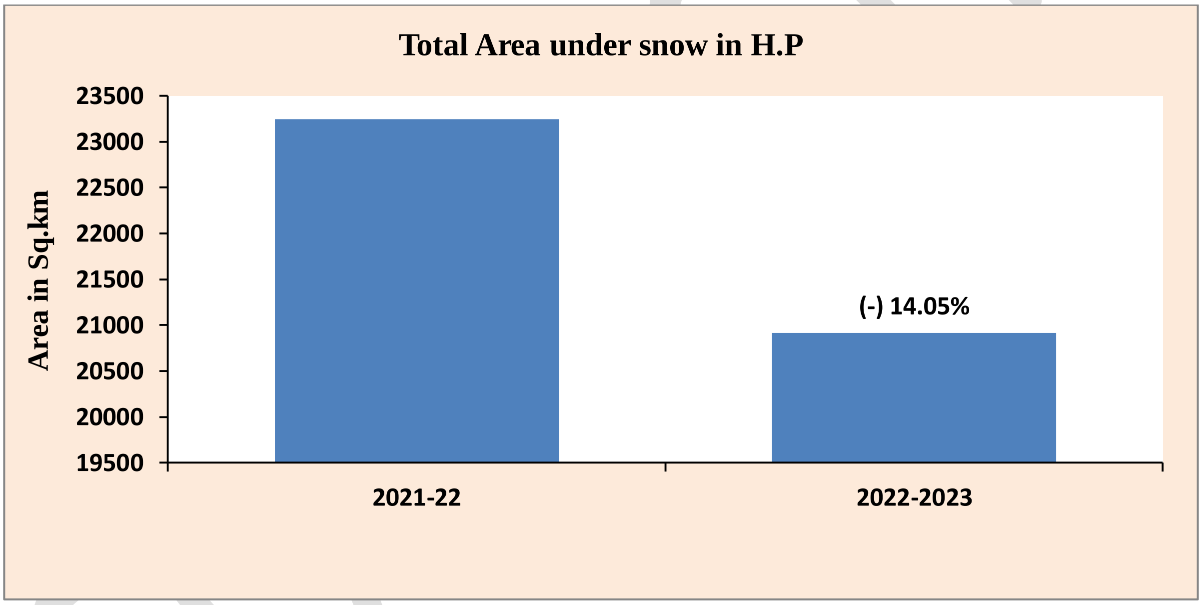


Fig. 3.3: Total Area under Snow in H.P

4. Temperature Trend Analysis between 2022 & 2023 in Himachal Pradesh:

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

Table 4.1: Mean Monthly Minimum and Maximum at Keylong

	Mean Monthly Temperature (°C)	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2018-19	Max	14.05	7.07	4.17	0.30	1.07	5.41	14.35
	Min	1.74	-3.15	-7.54	-10.35	-8.73	-4.61	2.67
2019-20	Max	16.05	6.19	0.32	-3.23	1.69	5.20	11.32
	Min	2.04	-2.35	-10.09	-9.96	-8.62	-4.45	0.41
2020-21	Max	18.65	6.31	1.93	0.93	4.29	8.17	9.64
	Min	2.68	-3.09	-7.38	-8.68	-5.46	-2.48	-0.48
2021-22	Max	15.08	10.00	2.71	-1.74	-0.06	9.23	16.71
	Min	2.85	-2.83	-6.99	-8.91	-8.91	-2.02	3.00
2022-23	Max	15.91	7.58	6.36	1.64	2.19	7.99	10.85
	Min	2.39	-3.31	-5.27	-7.40	-6.26	-2.01	0.04

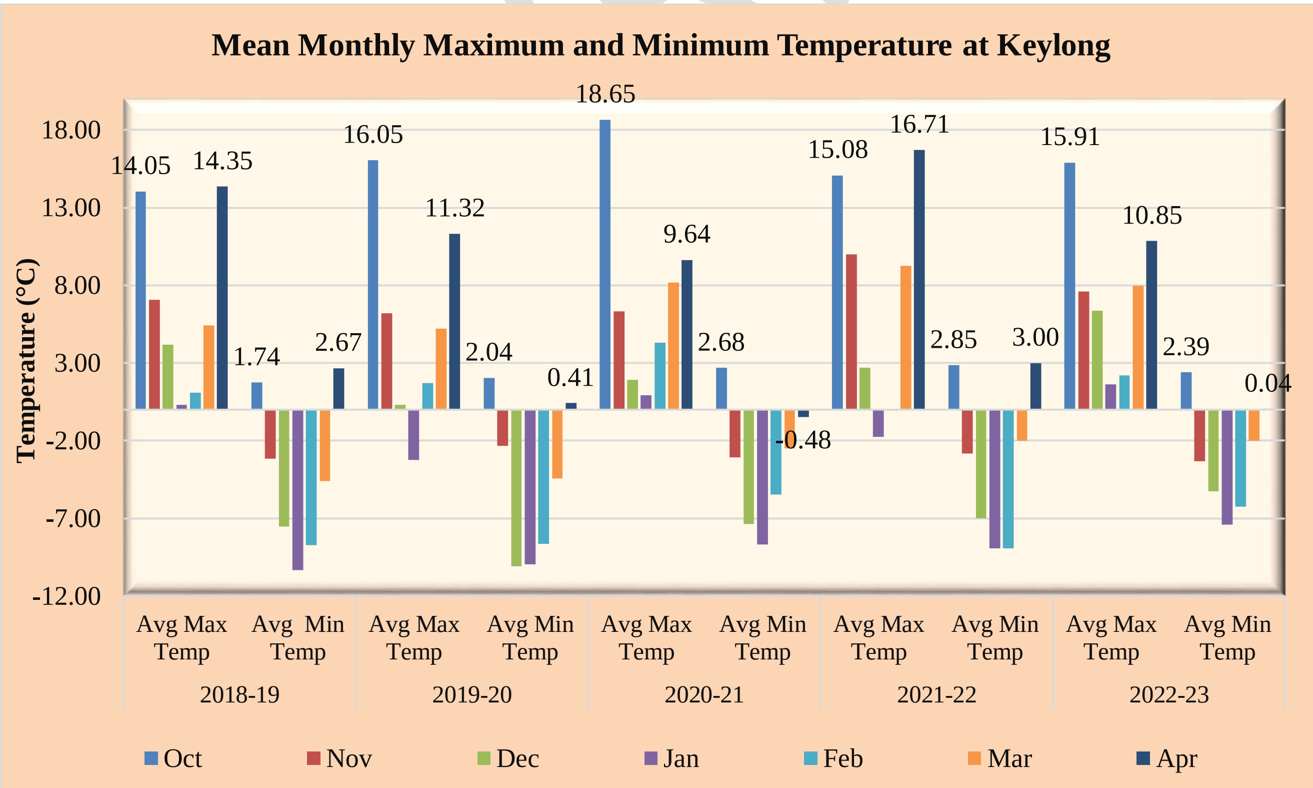


Fig. 4.1: Mean Monthly Maximum and Minimum Temperature at Keylong (2022-2023)

Table 4.2: Minimum and Maximum Temperature at Kalpa

	Mean Monthly Temperature (°C)	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2018-19	Max	18.29	13.34	9.13	3.94	5.65	11.18	19.76
	Min	4.75	1.10	-2.10	-4.89	-3.25	-0.06	5.33
2019-20	Max	18.05	11.85	5.53	1.16	5.66	11.10	16.00
	Min	4.84	1.75	-2.11	-5.23	-2.94	0.13	3.50
2020-21	Max	21.59	12.11	9.90	8.49	12.25	14.72	15.45
	Min	5.79	0.85	-1.28	-2.04	-0.77	1.59	2.67
2021-22	Max	18.69	15.32	8.39	4.30	7.17	17.44	21.92
	Min	5.92	1.00	-1.98	-3.49	-2.94	3.77	5.91
2022-23	Max	18.76	14.57	12.37	6.66	10.00	13.36	26.04
	Min	4.60	1.48	-0.84	-2.29	-0.42	1.55	3.24

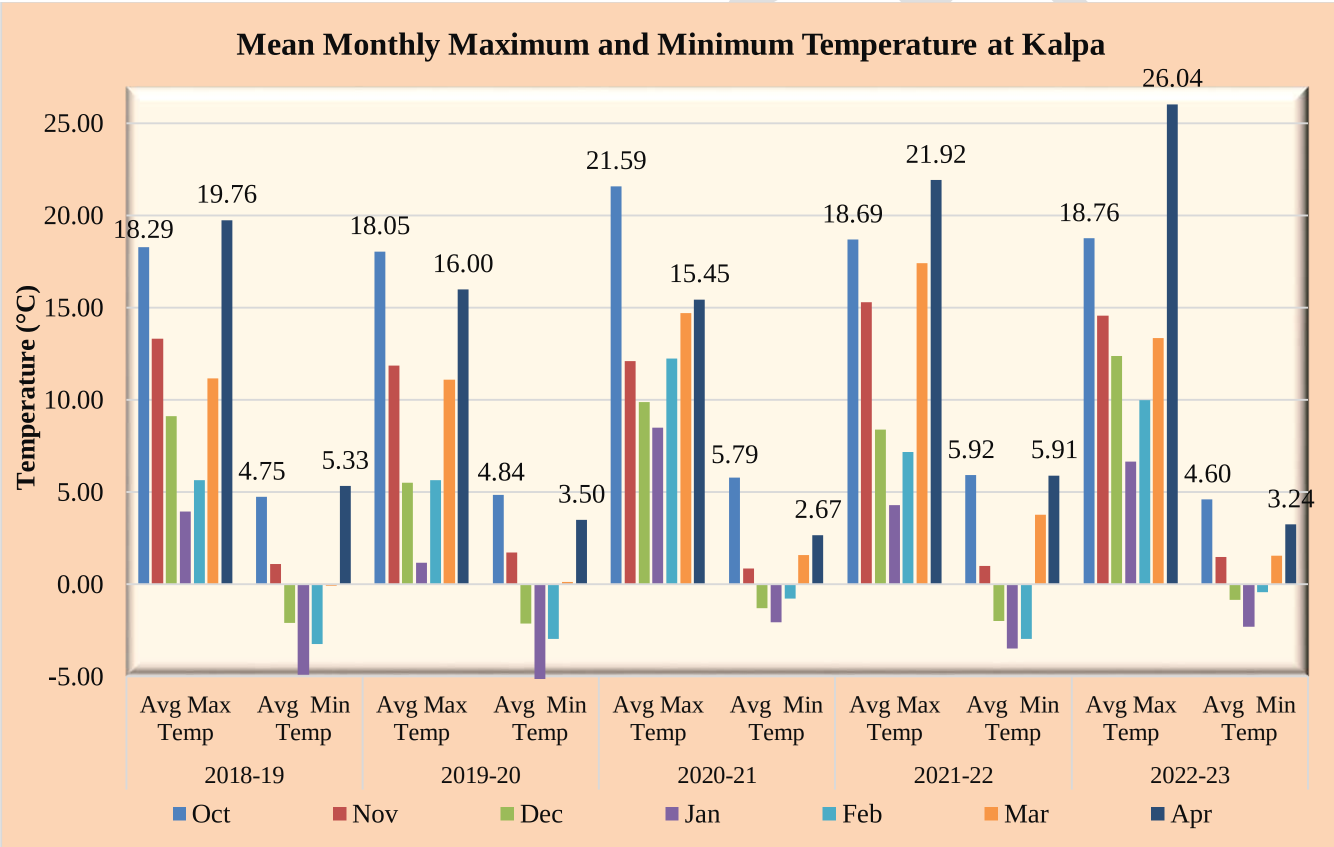


Fig. 4.2: Mean Monthly Maximum and Minimum Temperature at Kalpa (2022-2023)

Table 4.3: Minimum and Maximum Temperature at Bhuntar

	Mean Monthly Temperature (°C)	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2018-19	Max	27.22	20.95	17.95	14.99	17.54	21.97	29.18
	Min	10.08	5.43	1.08	2.13	4.73	6.64	11.01
2019-20	Max	27.32	20.96	17.66	14.09	20.60	21.19	26.12
	Min	10.37	7.36	1.26	2.91	4.04	6.98	10.44
2020-21	Max	30.40	20.99	18.50	18.59	22.08	25.18	27.03
	Min	10.84	5.43	2.14	2.37	4.79	7.81	9.00
2021-22	Max	27.52	23.39	18.22	15.51	18.13	27.78	32.42
	Min	12.23	4.54	2.67	3.62	3.53	8.12	10.77
2022-23	Max	27.51	22.52	19.99	16.89	21.43	23.28	26.04
	Min	10.86	5.09	1.53	2.99	5.15	8.22	9.60

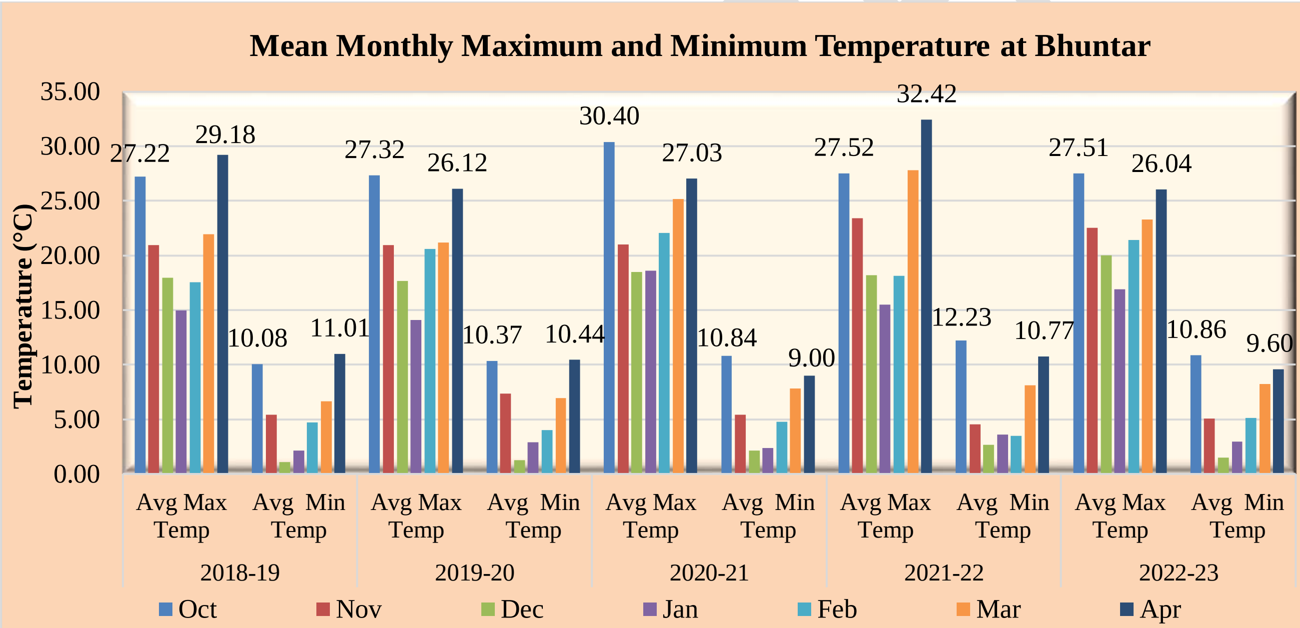


Fig. 4.3: Mean Monthly Maximum and Minimum Temperature at Bhuntar (2022-2023)

Table 4.4: Minimum and Maximum Temperature at Manali

	Mean Monthly Temperature (°C)	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2018-19	Max	19.69	13.82	11.25	7.70	11.01	14.61	22.61
	Min	5.91	2.61	-0.91	-1.63	0.76	2.21	7.22
2019-20	Max	19.25	13.72	10.85	7.11	13.83	14.17	19.36
	Min	5.95	3.45	-1.30	-2.51	-0.19	1.70	5.25
2020-21	Max	23.61	14.55	12.14	12.89	14.58	17.83	19.69
	Min	5.73	2.38	1.10	0.92	2.50	5.07	6.20
2021-22	Max	20.12	15.68	11.86	8.79	10.38	20.98	24.75
	Min	8.75	2.46	0.60	-0.23	-0.05	6.28	8.90

2022-23	Max	20.23	15.13	13.24	9.88	13.70	15.60	18.79
	Min	7.75	3.45	1.31	0.54	3.17	4.63	6.34

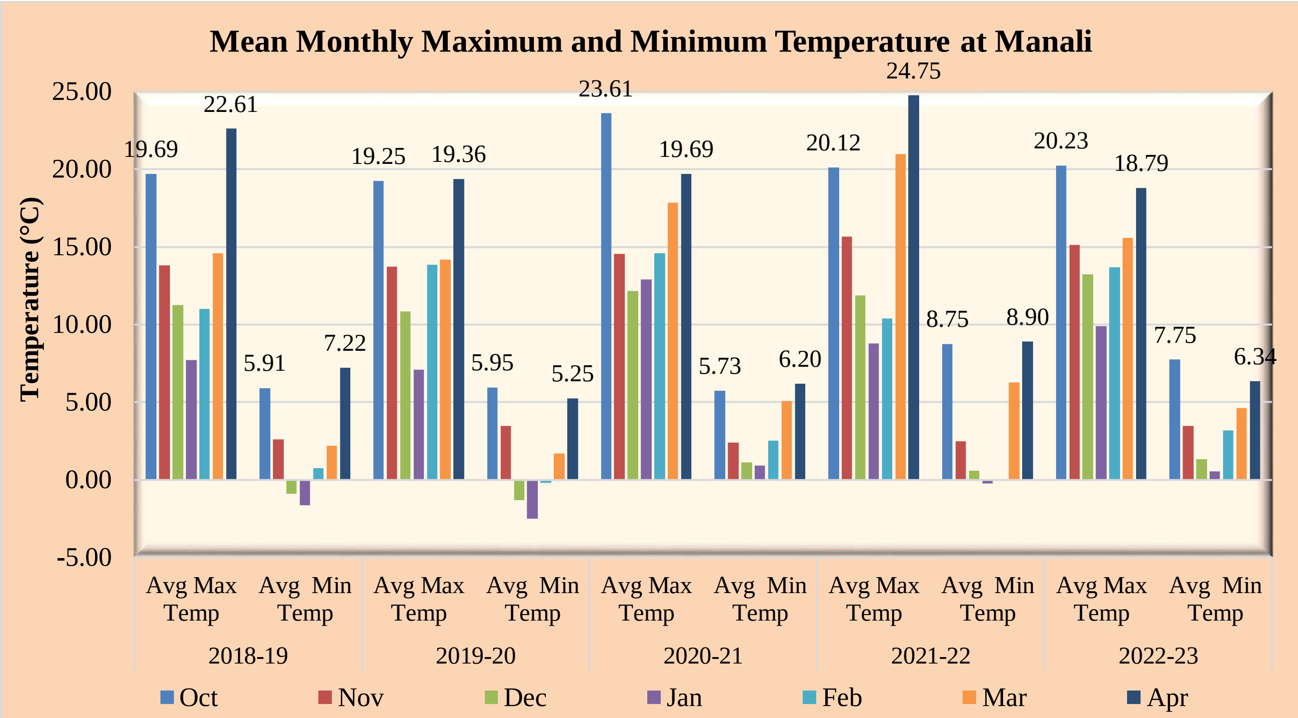


Fig. 4.4: Mean Monthly Maximum and Minimum Temperature at Manali (2022-2023)

Table 4.5- Minimum and Maximum Temperature at Chamba

	Mean Monthly Temperature (°C)	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
2018-19	Max	26.89	20.92	17.18	14.71	17.80	22.18	29.62
	Min	11.90	7.42	3.10	3.62	5.69	8.24	12.86
2019-20	Max	26.78	20.57	15.43	14.05	20.52	21.11	26.45
	Min	12.19	9.31	2.90	3.83	5.53	8.25	11.93
2020-21	Max	29.82	21.18	18.35	17.81	22.15	25.41	27.40
	Min	11.59	7.48	3.63	3.55	6.91	9.26	11.11
2021-22	Max	27.10	22.44	17.54	14.29	18.09	27.54	32.63
	Min	13.79	6.65	4.37	4.24	5.52	10.81	12.74
2022-23	Max	26.49	20.64	20.02	16.29	22.10	23.38	27.19
	Min	12.72	7.81	4.30	4.92	7.40	10.33	12.08

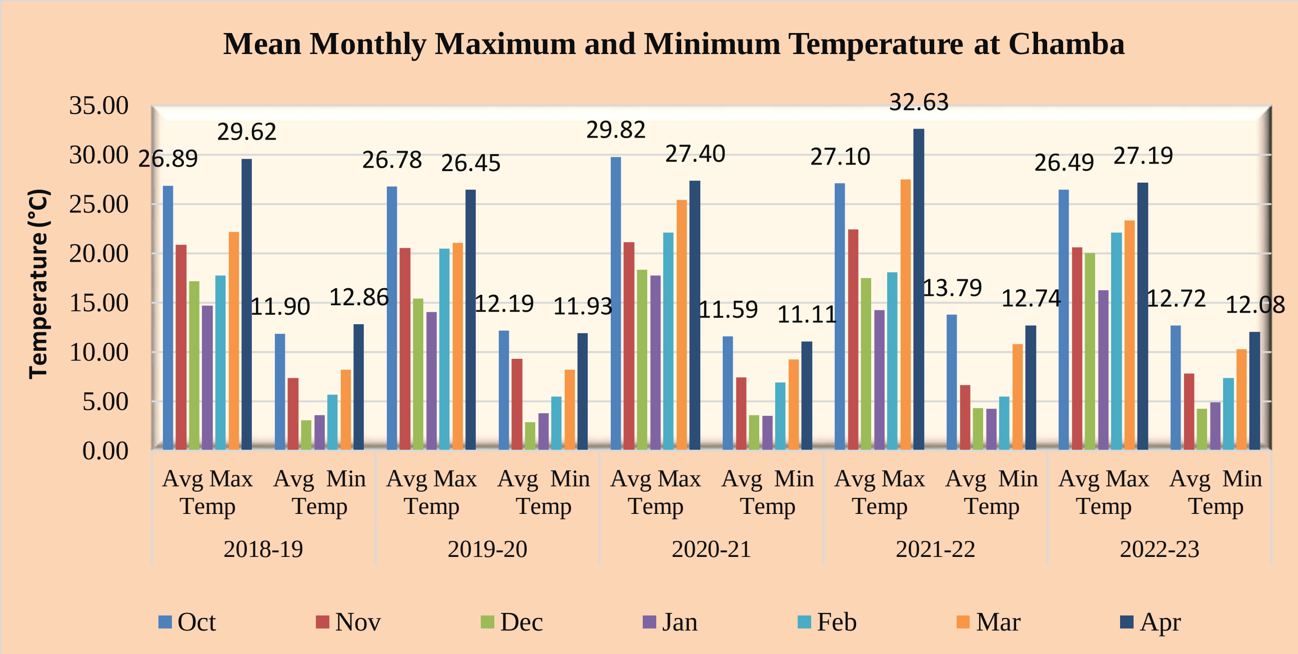


Fig. 4.5: Mean Monthly Maximum and Minimum Temperature at Chamba (2022-2023)

Table-4.6 Minimum and Maximum Temperature at Dalhousie

	Mean Monthly Temperature (°C)	Oct	Nov	Dec	Jan	Feb	Mar	Apr
2018-19	Max	15.91	12.50	8.87	6.28	8.18	10.77	18.34
	Min	11.02	7.83	4.28	1.15	2.99	5.68	11.91
2019-20	Max	15.90	11.98	8.77	4.85	9.79	9.29	14.91
	Min	10.97	6.97	3.88	-0.03	3.95	4.71	9.29
2020-21	Max	17.07	11.60	9.49	8.74	10.74	14.35	15.95
	Min	12.30	6.61	4.80	4.06	5.55	8.08	10.07
2021-22	Max	16.69	12.82	8.94	5.92	7.64	15.37	22.56
	Min	12.04	7.88	3.71	1.77	2.35	9.53	14.57
2022-23	Max	18.66	14.64	12.32	8.37	13.85	13.01	17.23
	Min	11.74	8.56	6.42	3.14	7.36	7.17	9.82

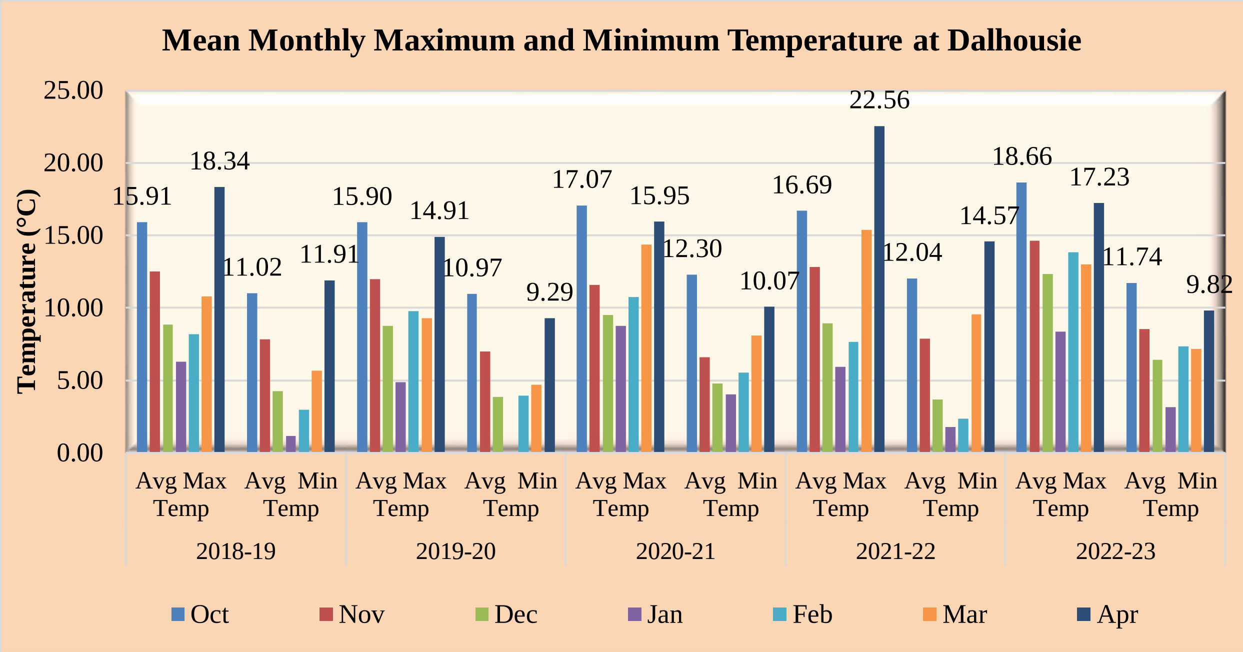


Fig. 4.6: Mean Monthly Maximum and Minimum Temperature at Dalhousie (2022-2023)

Descriptive Analysis of Maximum and Minimum Temperature -

Table 4.7 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 4.7: 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 devaiation, 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 **fig. 4.7 and fig. 4.8** and **table 4.8**.

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.

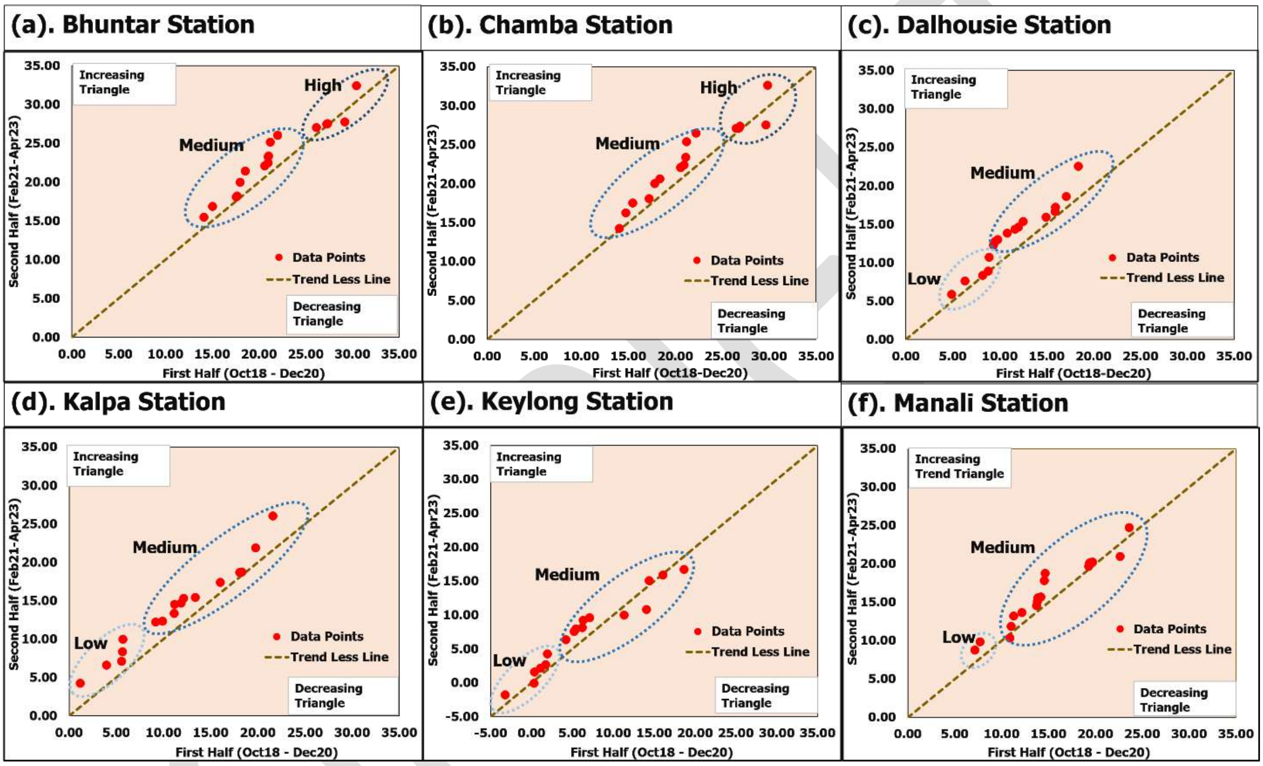


Fig.4.7 - Mean monthly trend of maximum temperature for the snow accumulation months of October to April (2018 - 2023) using ITA method of the selected six stations

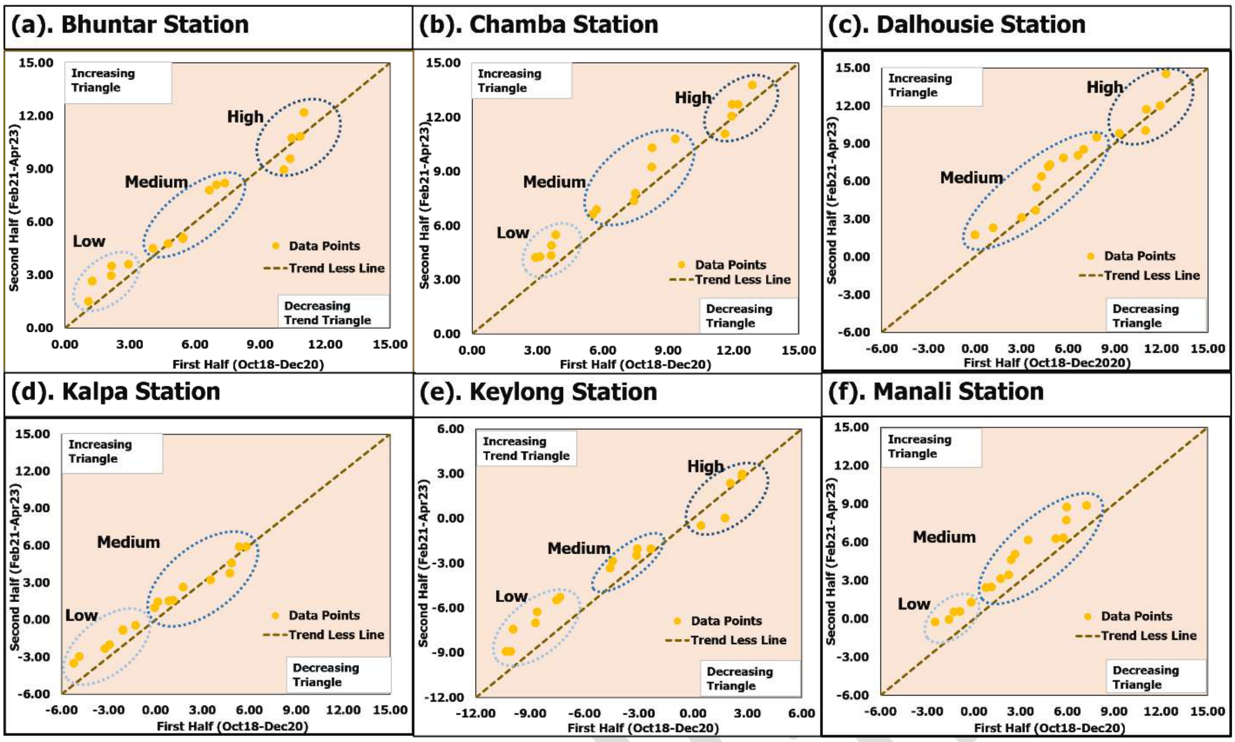


Fig.4.8: Mean monthly trend of minimum temperature for the snow accumulation months of October to April (2018 - 2023) using ITA method of the selected six stations

Table 4.8: Details of mean monthly trend of maximum and minimum temperature for the selected six stations

Stations	Variables (°C)	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	↓
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, ↓ – Decreasing trend

5. Conclusion:

- Based on the analysis carried out for the mapping of seasonal snow cover during 2022-23 winters from October to April and its comparative analysis made w.r.t 2021-22 winters, the following inferences were made:
- Basin wise analysis carried out from October 2022 to April 2023 and its comparative with that of the 2021-22 reveals that all the four basins under investigation i.e., Chenab, Beas, Ravi and Satluj shows varying results in the month of October wherein the Chenab basin occupies 53% of the total basin area under snow, whereas the other basins occupies as Beas (38%), Ravi (20%) and Satluj (22%) respectively. Based on the comparative analysis, it is found that Chenab basin shows a decline of about 36%, Ravi by about 54% and Satluj by about 27% in comparison to 2021-22 during the month of October, whereas the Beas shows a slight enhancement in its area under snow by about 3% in 2022-23.
- Likewise, in November, 83% of the total basin area was covered under snow in Chenab, about 44 % in Beas, 32% in Ravi and 34% in Satluj in 2022-23 with Chenab basin showing (5%) and Beas (21%) enhancement in its comparison to 2021-22, whereas the Ravi and Satluj shows a decline in its area under snow by about 3% (Ravi) and 22% (Satluj) in its comparison to 2021-22.
- In December about 80% of the total area in Chenab, 44% in Beas, 36% in Ravi and 23% in Satluj remained occupied under snow with all basins reflecting a declining trend in their area w.r.t 2021-22and the maximum decline was of the order of about 56% in case of Satluj basin and the least was of 10% in Chenab in their area under snow w.r.t 2021-22 results.
- Likewise in January, Chenab occupies about 89%, Beas (55%), Ravi (58%) and Satluj (41%) of the basin area under snow during 2022-23 winter period with all the basins showing a decline in their area w.r.t 2021-22 wherein Chenab (5%), Beas (16%) Ravi (3%) and Satluj (38%) in comparison to 2021-22 respectively.
- During February, 96 % of the basin area in Chenab, 32% in Beas, 12% in Ravi and 17% in Satluj basin was occupied by snow cover with all basins showing declining trend w.r.t 2021-22 winter period and decline was of the order of 4 % (Chenab), 32% (Beas), 12% (Ravi) and 17% (Satluj) basins respectively.
- Likewise in March, similar trend was observed with all basins showing decline in their area by about 2% (Chenab), 5% (Beas), 7% (Ravi) and about 4% (Satluj) basins w.r.t 2021-22

respectively, whereas basin wise coverage during 2022-23 was observed to be 90% (Chenab), 57% (Beas) ,42% (Ravi) and 41% (Satluj) basins respectively.

- At the start of the summer ablation period i.e., April, shows the enhancement in the area under snow in each basin, wherein Chenab shows enhancement by 22%, Beas by 39%, Ravi by 54% and Satluj by 29% in the area under snow during 2022-23 in comparison to 2021-22 with Chenab occupying 85% of the basin area, Beas as 51%, Ravi as 33% and Satluj as 43% under snow in during April 2023 respectively.
- Thus, during early winter months (October to November), the only enhancement could be seen in case of Beas basin during both months, whereas Chenab shows a marginal increase in November only and the other two basins i.e., Ravi and Satluj a negative trend.
- During peak winter months (December to February), there was decline in the area under snow in 2022-23 in comparison to 2021-22 with maximum decline was observed in Satluj basin and the minimum was in Chenab basin. Almost same retreating trend was observed in each basin in March with some slight variations. At the beginning of the ablation period i.e., April, the winter precipitation extended to April as a result of which an enhancement of area seen in each basin.
- As a whole based on the analysis, it is observed that in Chenab basin 4.18% decline has been observed in 2022-23 in comparison to 2021-22, whereas in Beas the decline is of the order of 9.06%, in Ravi 10.02% and in Satluj, the decline is of the order of 22.20% in 2022-23 in comparison to 2021-22 in terms of the total spatial distribution of the snow cover area.
- Further analysis reveals that as a whole about 14.05% decline could be seen in the entire H.P. Himalaya covering all the four basins i. e Chenab, Beas, Ravi and Satluj based on the monthly average of the area under snow cover in each basin in 2022-23 in comparison to 2021-22.
- Further analysis of area under snow in March and April (2022-23) reveals that in Chenab basin about 4% of the total basin area has been vacated out from the snow i.e. melted out in comparison to 25% between March & April (2021-22) , where as in Beas basin it is of the order of about 5% in comparison to 23% of 2021-22, about 8% in Ravi and Satluj basin each during these two months in comparison to 24% and 19% during 2021-22 respectively and the large variation is mainly due to fresh snow fall in April 2023 reflecting positive trends in each basin.
- While analyzing the IMD data for 2018 & 2023 during the months of October to April for mean maximum, & mean minimum temperatures in Himachal Pradesh in different basins with point data at Kelyong (Chenab basin), Manali & Bhuntar (Beas basin), Chamba & Dalhousie (Ravi

basin) and Kalpa (Satluj basin), a very sharp prominent increasing trend in the maximum and minimum temperature was observed at all four-point locations representing each basin.

- Based on the plotting of the temperature data and the 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 and the increase is at the rate of 0.31^0C /month for maximum temperature but for minimum temperature, the decreasing trend was observed with the rate of -1.18^0C/month and the results obtained are in line with the similar work carried out by Rathore et.al (2018) for the time period 2004 to 2018.
- Further analysis temperature revels that majority of stations have reflected non-monotonic increasing trend for maximum and minimum temperature except Dalhousie and Manali that showed monotonic increasing trend.

6. Concluding Remarks:

Thus, 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 14.05% 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.

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