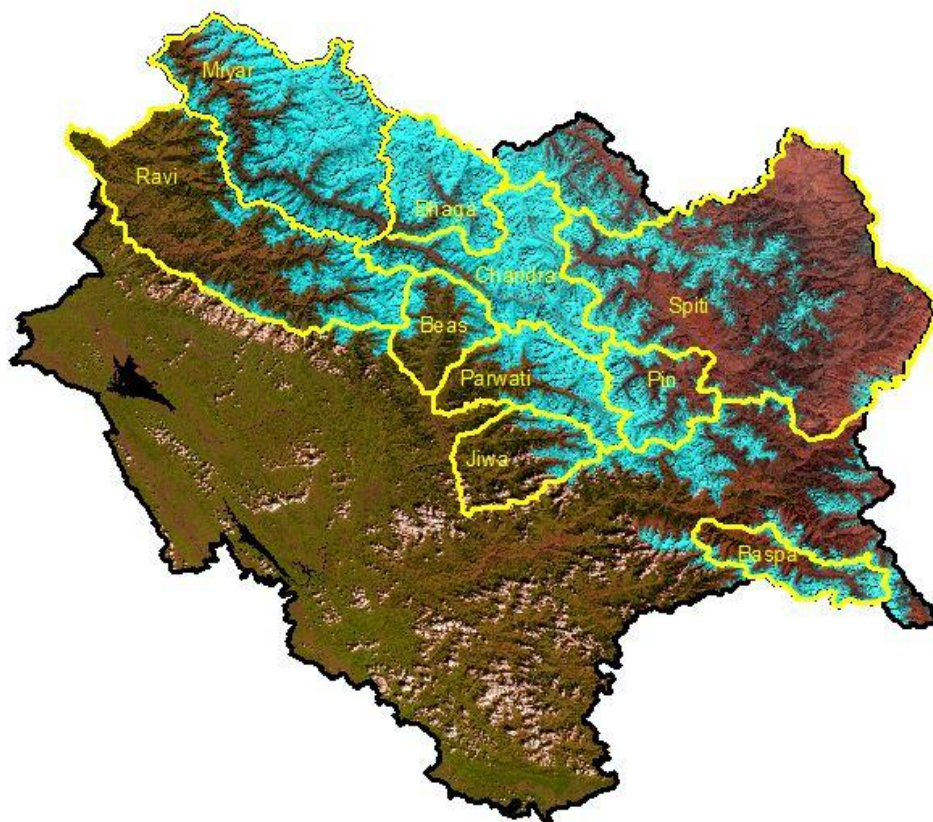


***ASSESSMENT OF SPATIAL DISTRIBUTION OF
SEASONAL SNOW COVER DURING THE YEAR 2018-19
IN HIMACHAL PRADESH USING SPACE DATA***



Prepared By

H.P State Centre on Climate Change
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(HIMCOSTE)
&
(Space Applications Centre, ISRO, Ahmedbad)

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ASSESSMENT OF SPATIAL DISTRIBUTION OF SEASONAL SNOW COVER DURING THE YEAR 2018-19 IN HIMACHAL PRADESH USING SPACE DATA

1. Introduction:

Snow is a type of precipitation in the form of crystalline ice, consisting of a magnitude of snowflakes that fall from clouds. Snow is composed of small ice particles. It is a granular material. The process of this precipitation is called snowfall. The density of snow when it is fresh is $30\text{-}50\text{kg/m}^3$. When it becomes firm the density becomes about $400\text{-}830\text{ kg/m}^3$. Snow becomes glacier ice when density is $830\text{-}910\text{ kg/m}^3$. Snow becomes firm when it survives for minimum one summer and becomes glacier ice in many years. Density increases due to remelting and recrystallization and reduction in air spaces within the ice crystals.

The required atmospheric conditions for snow fall are met at higher latitudes and altitude of the earth. There are three major classes of snow cover i.e. temporary, seasonal and permanent. Temporary and seasonal snow-cover occurs in winters while permanent snow cover is retained for many years. In terms of spatial extent, snow cover is second largest component of the cryosphere and covers approximately 40-50% of earth's land surface during Northern hemisphere winter (Hall et al., 1995; Pepe et al., 2005).

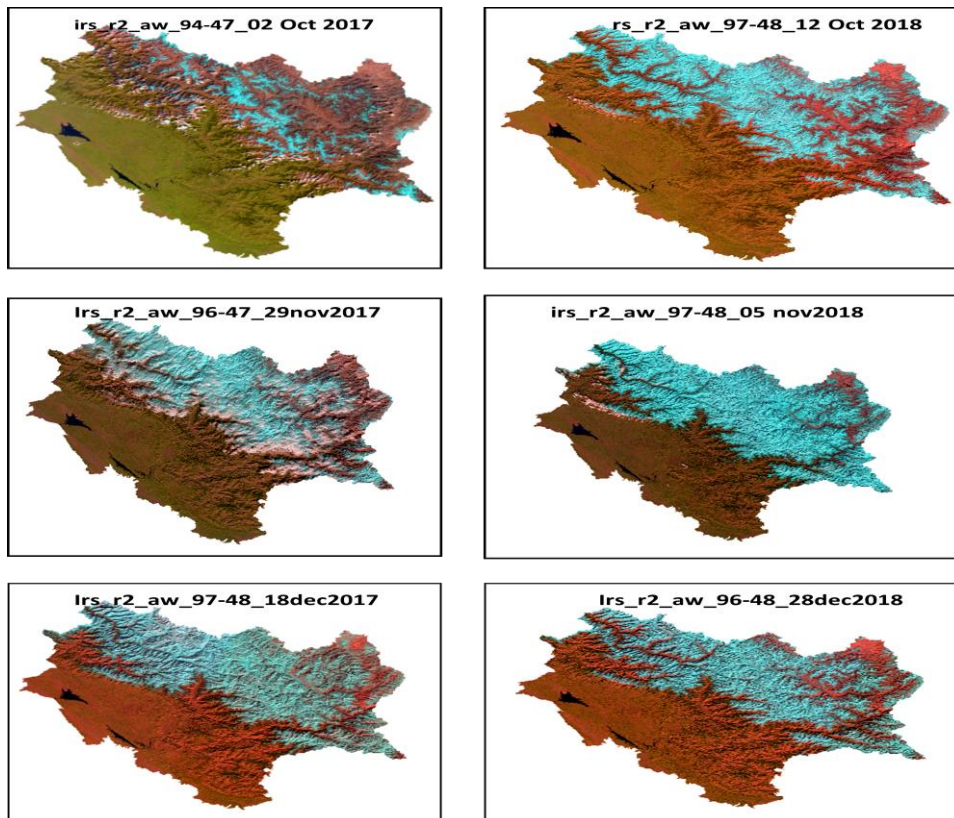
Snow is an essential resource present in the Himalaya. Therefore, monitoring of the snowfall changes over a time period is important for hydrological and climatological purposes. Snow covers almost 40 per cent of the Earth's land surface during Northern Hemisphere. This makes albedo and areal extent of snow as important component of the Earth's radiation balance (Foster and Chang, 1993). In addition, large areas in the Himalayas are also covered by snow during winter. Area of snow can change significantly during winter and spring. This can affect stream flow for rivers originating in the higher Himalayas. All the rivers originating from higher Himalayas receive almost 30-50 % of annual flow from snow and glacier melt run off (Agarwal et al., 1983). In addition, snow pack ablation is highly sensitive to climatic variation. Increase in atmospheric temperature can influence snowmelt and stream runoff pattern (Kulkarni et al., 2002). Therefore, mapping of the areal extent and reflectance of snow are important

parameter for various climatological and hydrological applications. In addition, extent of snow cover can also be used as input for numerous other applications.

Mapping and monitoring of seasonal snow cover using field methods are normally very difficult in a mountainous terrain, like the Himalayas. Therefore, remote sensing techniques have been extensively used for snow cover monitoring. Snow cover monitoring using satellite images were started by using the TIROS-1 satellite from April 1960 (Singer and Popham 1963). Since then, the potential for operational satellite-based mapping has been enhanced by the development of higher temporal frequency and satellite sensors with higher spatial resolution. In addition, satellites with better radiometric resolutions, such as NOAA have been used successfully for snow mapping (Hall et al., 1995). This is possibly due to the distinct spectral reflectance characteristics of snow in visible and near infrared regions. India has launched series of Indian Remote Sensing satellite (IRS) to study the different earth resources. Previously launched satellites have flown with many sensors having different spatial, temporal and spectral In addition, satellites with better radiometric resolutions, such as NOAA have been used successfully for snow mapping (Hall et al., 1995). This is possibly due to the distinct spectral reflectance characteristics of snow in visible and near infrared regions. India has launched series of Indian Remote Sensing satellite (IRS) to study the different earth resources. Previously launched satellites have flown with many sensors having different spatial, temporal and spectral resolutions. Recently launched RESOURCESAT-1 satellite has three different sensors namely LISS III, LISS IV & AWiFS with different spatial, temporal and spectral resolutions as desired for different applications. AWiFS (Advanced Wide Field Sensor) is an advanced version of earlier Indian satellite sensor WiFS (Wide Field Sensor) with improved spectral and spatial resolutions maintaining the same repetivity. There are a series of other polar orbiting satellites, like Landsat, NOAA and MODIS etc., which have provided information on different aspects of snow. Geo-stationary satellites also proved their utility in mapping/monitoring the snow-covered regions. Information generated from satellite observations has been extensively used for snowmelt runoff modeling (Kulkarni et al., 1997).

2. Background:

Concern over changes in global climate caused by rising atmospheric concentrations of carbon dioxide and other trace gases has increased in recent years as our understanding of atmospheric dynamics and global climatic systems has improved relatively. The snowfall events have been greatly influenced by climatic changes. These are thought to oscillate in two important ways: (1) reductions in the intensity of snowfall and (2) changes in the timing of snowfall. The rise in temperature associated with climate change leads to a general reduction in the proportion of precipitation falling as snow, and a consequent reduction in many areas in the duration of snow cover, although the absolute amount of snowfall may increase if precipitation increases during the winter season. The timing of the snowfall had undergone a change. The onset of early snow in December and January had occurred more infrequently over time and the period of snowfall now extended through the months of February and March. But 2018-19 is an exceptional year of heavy snowfall from 2010 onwards. Snow products prepared using satellite images by auto extraction approaches have been analysed to know the Recent trends in the snow cover variability .The increased snow cover has been observed from 2017-18 to 2018-19. **Figure 2.1** is showing the heavy snowfall received in the year 2018-19 compared to 2017-18.



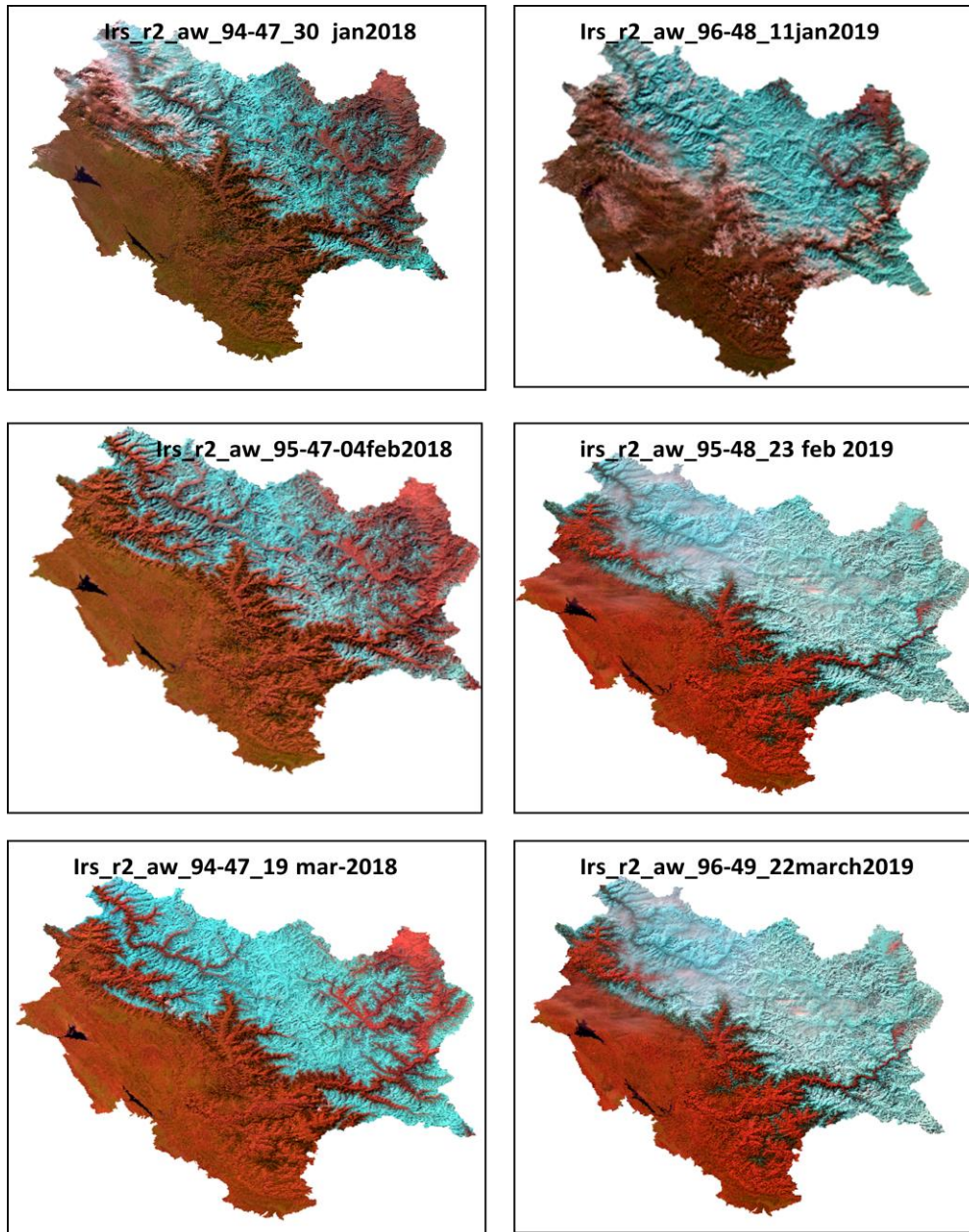


Figure 2.1: Satellite Images of H.P for the month of (Oct –March)2017-18/2018-19

3. Study Area:

Himachal Pradesh is a mountain province in the Indian Himalayas covering an area of over 55 thousand sq. km, where mountains and hills occupy most of the land. It extends from the Shivalik hills in the south to the Great Himalayan Range including a slice of Trans-Himalayas in the north. Geographically, the state of Himachal Pradesh is situated between 30°22'44'' and 33°12'40'' N latitude, and 75°45'55'' to 79°04'20''E longitude. In Himachal Pradesh, the sources of its major rivers and the bulk of its freshwater resources are locked up in ice and snow. Himachal Pradesh is divided into four major river basins viz., Chenab, Ravi, Beas, Satluj and their sub basins.

Chenab Basin: The Chandra Bhaga and Miyar rivers are the main drainage lines of Chenab basin. Chenab has a catchment area of 61,000 km² out of which approx 8,500 km² lie in Himachal Pradesh. It is the longest river of Himachal Pradesh in terms of volume of waters. The river is fed by numerous glaciers distributed throughout the basin.

Ravi Basin: The Ravi river basin extends from 32° 13' N to 33° 03' N latitude to 75° 46' E to 77° 01' E longitude. It is the smallest of the four major river basins of Himachal Pradesh

Beas Basin: The western part of Himachal Pradesh is occupied by the Beas river basin. It lies between 31°24' N - 32° 36' N latitude and 75° 36' E - 77° 52' E longitude. Glaciers are confined to the extreme north eastern part of the basin.

Satluj Basin: Satluj is the longest and largest river traversing the Pradesh from east to west. It spreads over 30° 22' to 32° 42' N latitude and 76° to 79° E longitude horizontally. Eighty percent of its catchment is snow fed. number of glaciers in Satluj basin is comparatively high, the ice reserve and the area occupied is less than the Chenab basin.



Figure: 3.1 Location Map of Study Area

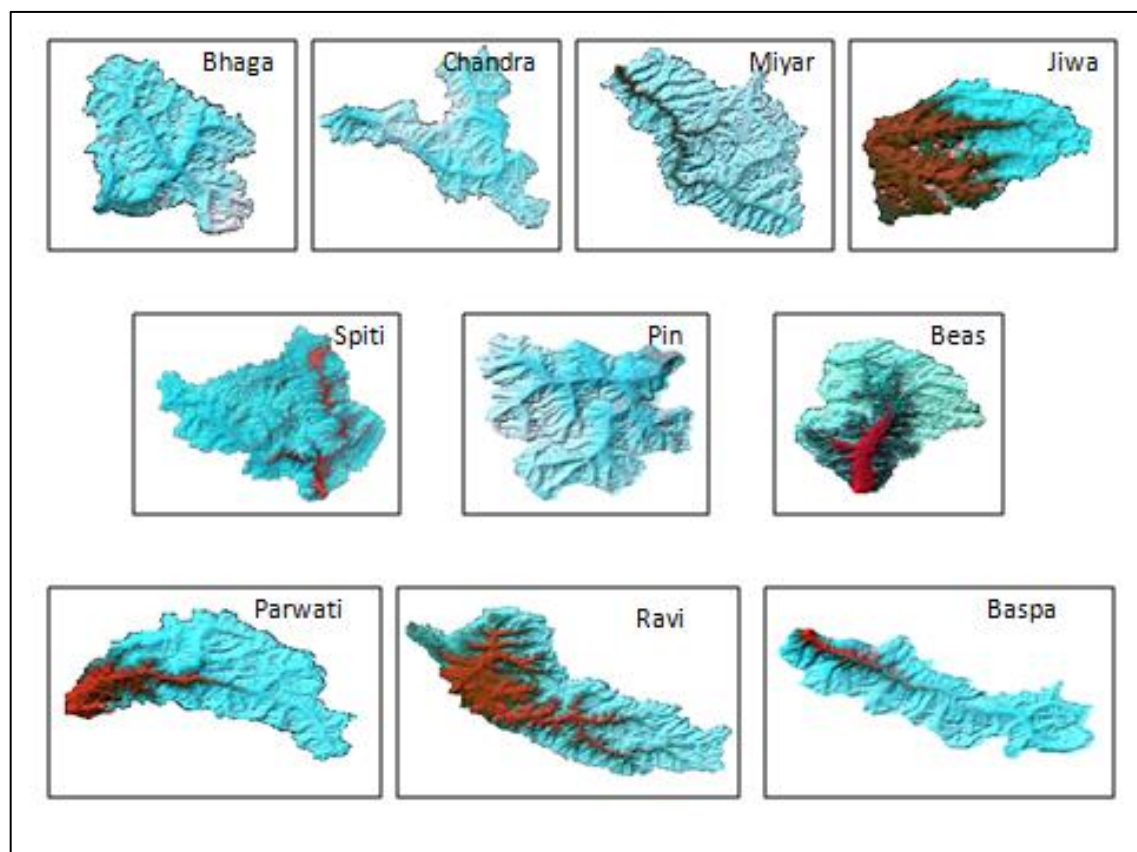


Figure 3.2 : River Basin of Himachal Pradesh

4. Methodology:

Normalized Difference Snow Index (NDSI):

In general, the reflectance of snow is high at the red end of the visible spectrum. It tends to decline in the near-infrared region until 1090 nm, where slight gain in reflectance occurs and gives a minor peak at approximately 1090 to 1100 nm. One of the important difficulties in snow cover monitoring is the presence of cloud cover. Cloud has strong reflectivity in visible, NIR and SWIR regions while snow absorbs in SWIR, and this difference can be utilized for snow/cloud discrimination. Normalized Difference Snow Index (NDSI) utilizes the normalized ratio of green and SWIR and is 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:

$$\text{Normalised Differential Snow Index (NDSI)} = (band2 - band5) / (band2 + band5)$$

To estimate NDSI, DN numbers were converted into reflectance. This involves conversion of digital numbers into the radiance values, known as sensor calibration, and then estimation of reflectance from these radiance values and the final product after running algorithm models is shown in **figure 4.1**. Various parameters needed for estimating spectral reflectance are maximum and minimum radiances and mean solar exo-atmospheric spectral irradiances in the satellite sensor bands, satellite data acquisition time, solar declination, solar zenith and solar azimuth angles, mean Earth-Sun distance etc. (Markham and Barker, 1987; Srinivasulu and Kulkarni, 2004).

Snow cover monitoring algorithm

An algorithm is developed to provide changes in the areal extent of snow (Kulkarni et. al., 2006). Snow extent is estimated at an interval of 5-days depending upon availabilities of AWiFS data. In 5-daily product, snow 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.

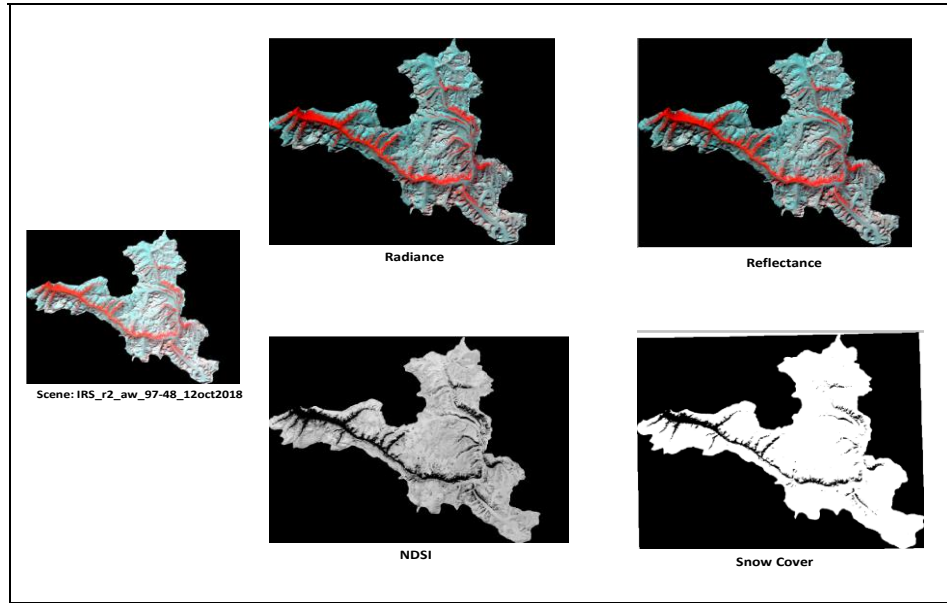


Figure 4.1: Extraction of snow cover area using 5 daily product.

5. 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 observed in all the basins viz Chandra, Bhaga, Miyar, Beas, Parvati, Jiwa, Pin, Spiti and Baspa. During 2018-19 snowfall was estimated and analyzed with reference to the averaged value of the total area under snow cover during the period 2017-18. Chenab basin which comprises of three sub basin (Chandra, Bhaga, Miyar) having total basin area (8562 km^2) and was analysed to assess the total area under snow during the year 2018-19 w.e.f october to March. On analysing the satellite data for the month of October 2018-19, it is found that the total area under snow has been increased by about 183.2% i.e. the area under snow in 2017-18 in the month of Oct which was mapped as 2121 km^2 has increased to 6007.65 km^2 in 2018-19. Likewise in November an increase of about 45% in comparision to 2017-18 has been observed i.e. the surface area has increased from 5377 km^2 (2017-18) to 7800.24 km^2 (2018-19). In December, an increase of about 17% has been observed in 2018-19 in the total area under

snow in Chenab Basin in comparison to the 2017-18 (6339 km²). Likewise January, February and March does not show much change in the total under snow in 2018-19 in comparison to 2017-18 which is reflected by 4.2% increase in January about 7% in February and about 5% in March in the Chenab Basin (**Table-5.1 & Figure-5.1**).

Table 5.1: Area under Snow in Chenab Basin

Name of the Basin	Observation Month	Area under Snow (Monthly Average) (2017-18) Km ²	Area under Snow (Km ²) 2018-19	area under snow cover (% change)
Chenab	October	2121.00	6007.65	183.2
	November	5377.32	7800.24	45.1
	December	6339.7	7440.82	17.4
	January	7679	8001.01	4.2
	February	7988.4	8567.05	7.2
	March	8111.0	8548.59	5.3

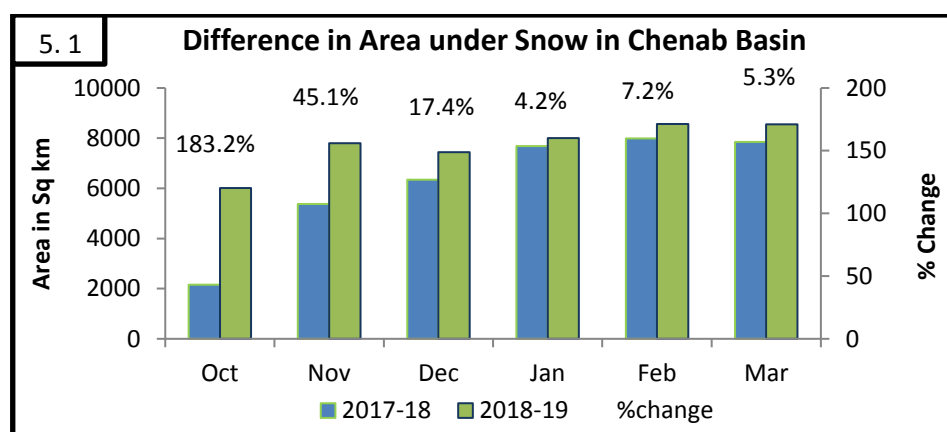


Figure 5.1: Difference in area under snow cover

Ravi Basin: The Ravi basin which is on the Southern side of the Pir Panjal range also shows the good amount of snowfall in all other months except December (2018-19). On analyzing the satellite data it is found that in October, the surface area has increased from 185.2 km² in 2017-18 to 946.68 km² in 2018-19. In the November spatial distribution of snow has increased from 829.23 km² (2017-18) to 1600.26 km² (2018-19) reflecting an overall increase of about 93% in 2018-19 in comparison to 2017-18. In December a decrease of about 11% has been observed in 2018-19 in comparison to 2017-18 i.e. the surface area has decreased to 2010.8 km² (2018-19) to 2271 km² (2017-18). In January the total area has increased from 1400.75 km² (2017-18) to 1937.57 km² (2018-19) indicating an

overall increase of about 38% in the Ravi basin. Likewise February and March shows an overall increase of 96% and 51% i.e the area has been increased from 2023 km² (2017-18) to 3966.92 (2018-19) in February and in March the surface area has increased from 2433.1 km² (2017-18) to 3677.72 km² (2018-19) (**Table-5.2 & Fig-5.2**).

Table 5.2 : Area under Snow in Ravi Basin

Name of the Basin	Observation Month	Area under Snow (Monthly Average) (2017-18) Km ²	Area under Snow (Km ²) 2018-19	Area under snow cover (% change)
Ravi	October	185.2	946.68	411.2
	November	829.23	1600.26	93.0
	December	2271.0	2010.8	-11.4
	January	1400.75	1937.57	38.3
	February	2023	3966.92	96.1
	March	2433.1	3677.72	51.2

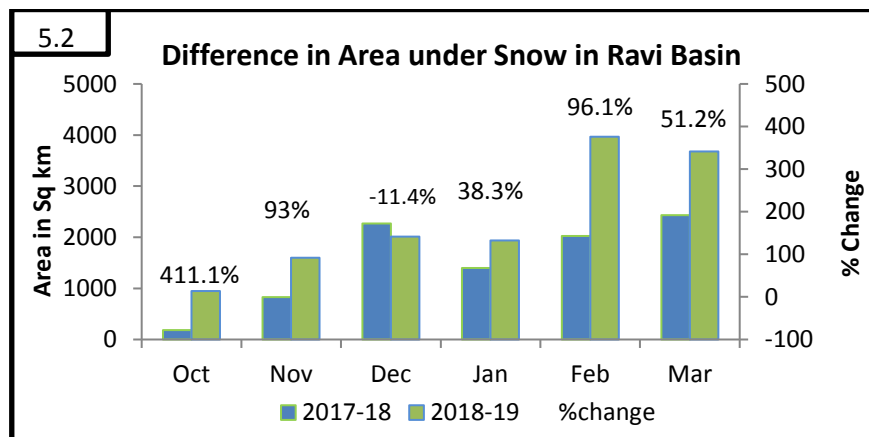


Figure 5.2: Difference in area under snow cover

Beas basin : The Beas basin lies between 31°24' N - 32° 36' N latitude and 75° 36' E - 77°.52' E longitude. Glaciers are confined to the extreme north eastern and northwestern part of the basin and also shows the good amount of snowfall in all winter other. On analyzing the satellite data it is found that in October the surface area has increased from 703.6 km² in 2017-18 to 1452.6 km² in 2018-19 reflecting an overall increase of about 106%. In November spatial distribution of snow has been increased to 1483.5 km² (2017-18) to 2264.76 km² (2018-19) indicating an increase of about 52% in 2018-19 in comparison to 2017-18. In December a decrease of about 16% has been observed in 2018-19 in comparison to 2017-18 i.e. the surface area has decreased to 2160.02 km² (2018-

19)from 2577.2 km² (2017-18) (Table 5.3 & Figure 5.3) During January not much change has been observed in 2018-19 which shows a 1.2% increase in January (Table-3& Fig-3.1). Likewise February and March does show an overall increase of 31% i.e. the area has been increased from 2410.4 km² (2017-18) to 3168.8 km² (2018-19) in February. Likewise in March the surface area has increased from 2644.8 km² in 2017-18 to 3456.5 km in 2018-19 shows an overall increase of 30.6%. (Table 5.3 & Figur)

Table 5.3: Area under Snow in Beas Basin

Name of the Basin	Observation Month	Area under Snow (Monthly Average) (2017-18) Km ²	Area under Snow (Km ²) 2018-19	Area under snow cover (% change)
Beas	October	703.6	1452.6	106.45
	November	1483.5	2264.76	52.66
	December	2577.2	2160.02	-16.18
	January	2136.5	2164.03	1.28
	February	2410.4	3168.8	31.46
	March	2644.8	3456.5	30.69

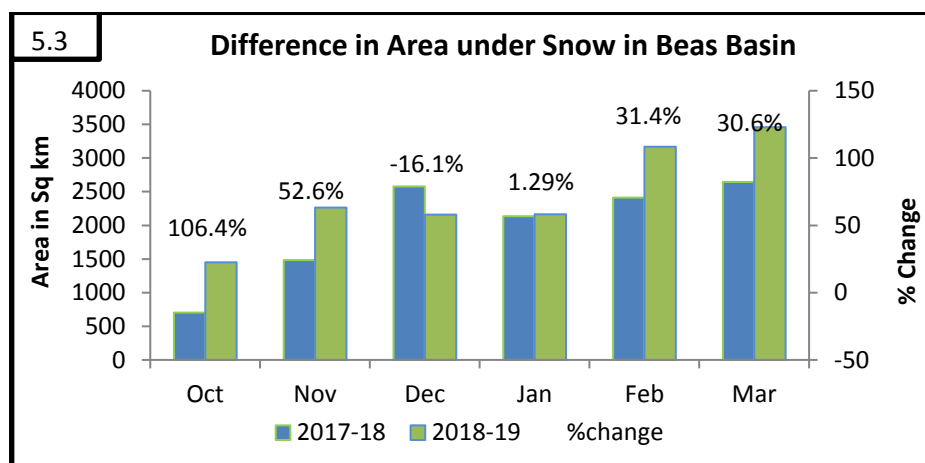


Figure 5.3: Difference in area under snow cover

Satluj Basin: Table 5.4 & Figure 5.4 depicts the total area under snow in Satluj basin. On the South eastern part of the state i.e. along Satluj basin, the basins viz. Baspa, Spiti, Pin are showing the similar trend of having maximum area under snow in the month of October 2018-19 than 2017-18. Figure 5.4 revealed the data analyzed for snow covered area between 2017-18 and 2018-19 for complete Satluj Basin. On

analysing the satellite data for the month of October 2018-19 it is found that the total spatial area of snow has been increased by about 185.2% i.e the area under snow in 2017-18 in the month of Oct was mapped as 1480.3 Km² has increased to 4222.4 km² in 2018-19. Likewise the November shows an increase of about 75% in comparison to 2017-18 i.e the surface area has increased from 3177.8 km² (2017-18) to 5569.59 km² (2018-19). Likewise December and January months shows a decrease of 0.95% and 0.05 % in 2018-19 (Table 5.4 & Figure 5.4). In February 2018-19 an increase of about 14.9% has been observed in the total area(10940 Km²) under snow in Satluj Basin in comparison to the 2017-18 which was 9516.5 km² in the same month. Likewise in March the surface area has increased from 9022.51 km² in 2017-18 to 10662.87 km in 2018-19 reflecting an overall increase of about 18%.(Table 5.4 & Figure 5.4).

Table 5.4: Area under Snow in Satluj Basin.

Name of the Basin	Observation Month	Area under Snow (Monthly Average) (2017-18) Km ²	Area under Snow (Km ²) 2018-19	area under snow cover (% change)
Satluj	October	1480.3	4222.4	185.2
	November	3177.8	5569.59	75.2
	December	7177	7108.75	-0.95
	January	8583.2	8578.08	-0.05
	February	9516.5	10940.7	14.9
	March	9022.51	10662.87	18.1

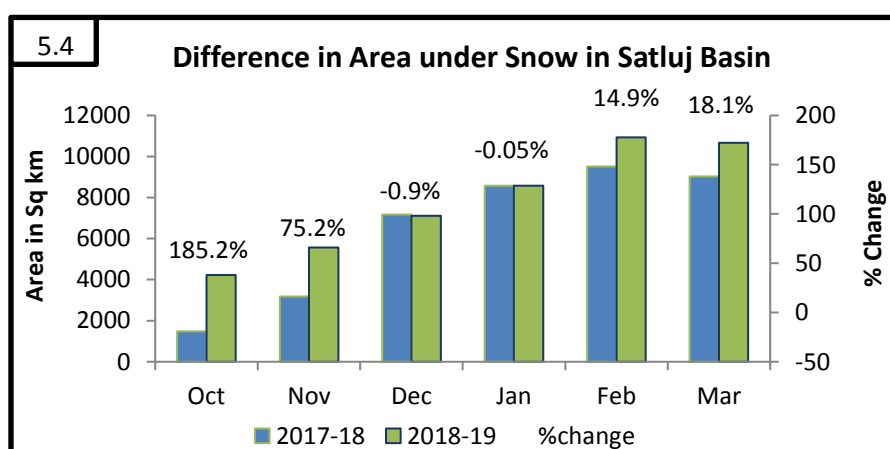


Figure 5.4: Difference in area under snow cover

The analysis and plotting of total area under snow from 2010-19 was also carried out in Himachal Pradesh. As per **Table 5.5**, Chenab basin in the month of October reflects that there is a decrease in the snow cover area from 2010-11 to 2014-15 and further increase in 2015-16 then reduction in 2017-18 followed by again increase in 2018-19 (**Figure.5.5a**). The least snow covered years during October were the 2014-15, 2017-18 and 2013-14 in the Chenab basin and maximum was observed in 2018-19. In November, there is a gradual increase in the total area under snow from 2010-11 to 2013-14 and further reduction in 2014-15 and which further increases from 2015-16 and 2017-18 and 2018-19 (**Figure.5.5b**). December month reflects a gradual increasing trend from 2010-11 to 2012-13 and beyond which it shows a fluctuating trend with reducing years in 2013-14 and 2014-15 beyond which it shows a increasing trend till 2018-2019 (**Figure.5.5c**). In January, almost a parallel trend could be seen up to 2013-14 beyond which a sudden fall is noticed in 2014-15 and then increasing trend in 2015-16, 2017-18 and 2018-2019 (**Figure 5.5 d**), whereas February shows more than 95% area under snow from 2010-11 to 2013-14 and then slight reduction in 2014-15 and 2015-16 followed by an increasing trend in 2017-18 and 2018-19 respectively (**Figure 5.5e**) and likewise March also shows more or less the similar trend as that of February. In general, the analysis of the total area under snow during 2010-18 in the month of October in Chenab basin reflects that the least snow covered years were the 2014-15 and 2017-18 which proportionally behaves similar in the other months during the same period.

Table-5.5: Area under snow in Chenab basin

Chenab Basin Total Area-8562 Km ²																
	2010-11	%	2011-12	%	2012-13	%	2013-14	%	2014-15	%	2015-16	%	2017-18	%	2018-19	%
Oct	4306.34	50.2	4054.81	47.3	3700.97	43.2	2641.33	30.8	1855.56	21.67	3157.17	36.8	2121	24.7	6007.65	70.17
Nov	4168.06	48.6	4363.22	50.9	4632.35	54.1	5824.66	68.0	2816.07	32.89	6215.22	72.5	5377.32	62.8	7800.24	91.10
Dec	3960.65	46.2	5674.46	66.2	8150.05	95.1	5906.33	68.9	4629.96	54.08	6113.09	71.3	6339.7	74.0	7440.82	86.91
Jan	8204.91	95.8	8559.34	99.9	8198.27	95.7	8271	96.6	6641.41	77.57	7306.64	85.3	7679	89.6	8001.01	93.45
Feb	8560	99.9	8554.29	99.9	8493.84	99.2	8448	98.6	7335.42	85.67	7643.23	89.3	7988.4	93.3	8560.05	99.98
March	8325	97.2	8456.80	98.7	8328.39	97.2	8473	98.9	8394.3	98.04	7002.28	81.7	8111.0	94.7	8548.59	99.84

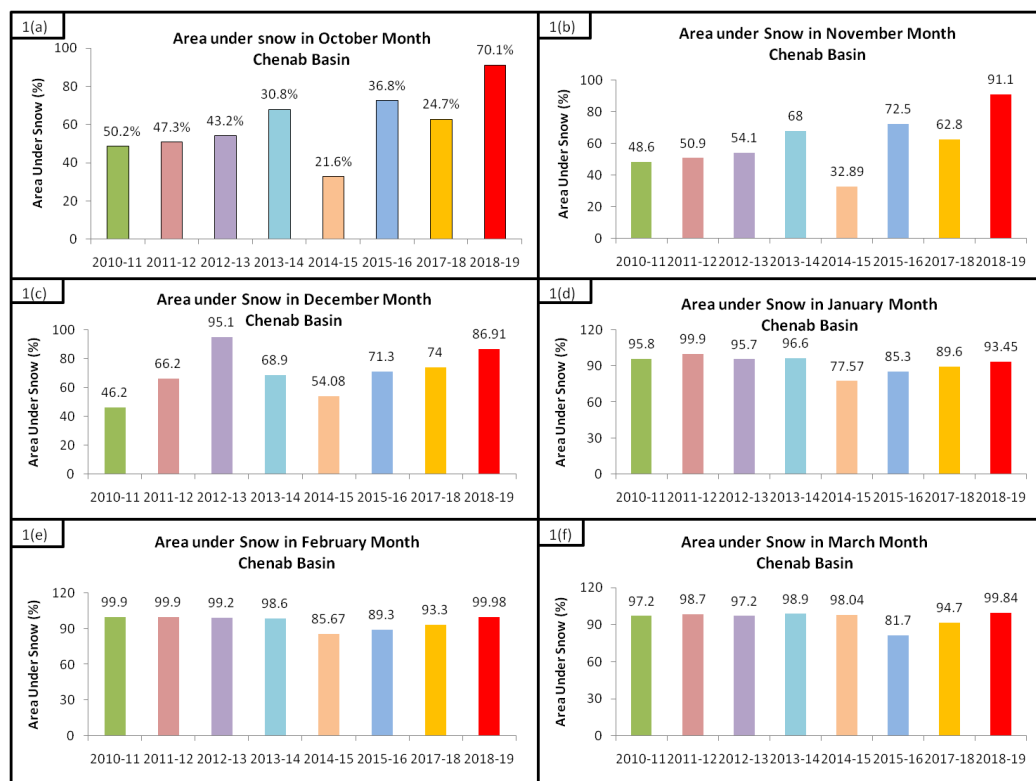


Figure 5.5: Area under snow cover in Chenab basin (a-f)

Analysis of the monthly area under snow (2010-19) in Ravi basin depicts that the total area snow in the month of October decreases from 2010-11 to 2014-15 gradually and thereafter it increases in 2015-16 (7%) and then further reduced to 3.7 % in 2017-18 and drastic increase of 19.2% in 2018-19 (**Figure 5.6a**). In the month of November, it increases gradually from 13.3% (2010-11) to 23.1% (2013-14) and then decreases to 9% (2014-15) and then further increased to 22% (2015-16) followed by reduction to 17% (2017-18) and increased to 32.6% respectively (**Figure.5.6b**). In December, the snow cover area increases from 14% (2010-11) to 60% (2012-13) and then follows a reducing trend from 2013-14 to 2015-16 (46% to 23%) beyond which increased to 46.2% in 2017-18 and further decreased to 40.9 % in 2018-19 (**Figure 5.6c**). In January maximum area covered under snow observed to be less than 70% up to 2013-14, whereas during peak winter months during 2014-15 to 2018-19, the snow covered area is less than 40%, whereas in March, maximum area under snow cover during the year 2014-15 with least area of 35% in 2015-16 followed by 49.6 % in 2017-which is increased up to 74.9% in 2018-19 (**Figures. 5.6d to 5.6f**)

Table 5.6: Area under snow in Ravi basin

Ravi Basin																
Total Area-4907 Km²																
	2010-11	%	2011-12	%	2012-13	%	2013-14	%	2014-15	%	2015-16	%	2017-18	%	2018-19	%
Oct	1059.7	21.5	810.93	16.5	517.18	10.5	425	8.6	197.8	4.0	367.55	7.4	185.2	3.7	946.68	19.2
Nov	656.08	13.3	755.03	15.3	798.80	16.2	1137	23.1	452.51	9.2	1092.28	22.2	829.39	16.9	1600.26	32.6
Dec	675.14	13.7	1352.82	27.5	2960.79	60.3	2257	45.9	1113.76	22.6	1138.54	23.2	2271	46.2	2010.8	40.9
Jan	2977.13	60.6	4552.98	92.7	3011.13	61.3	3055	62.2	1723.49	35.1	1702.36	34.6	1400.75	28.5	1937.57	39.4
Feb	3111.79	63.4	4160.26	84.7	3263.98	66.5	3442	70.1	1515.31	30.8	1805.00	36.7	2023.0	41.2	3966.92	80.8
March	2723.23	55.4	3126.08	63.7	2485.71	50.6	3101	63.1	3733	76.0	1757.00	35.8	2433.1	49.6	3677.72	74.9

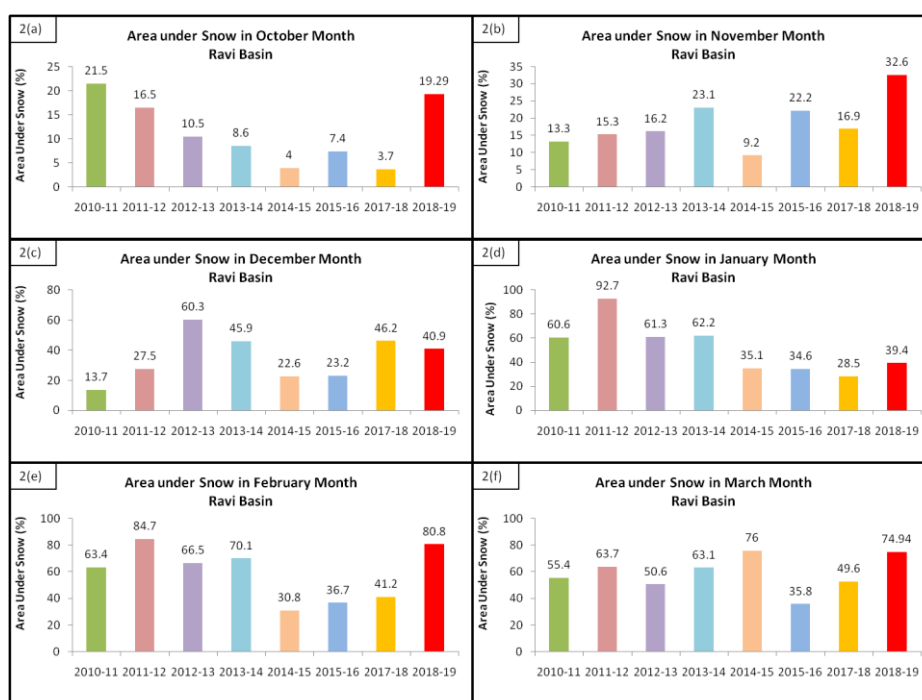


Figure -5.6: Area under snow cover in Ravi Basin (a-f)

From the analysis of the monthly area under snow in Beas basin in the month of October, it is found that the maximum area under snow that could be observed is of the order of 31.9 % in 2010-2011 and 33.3 % in 2018-19, where as in between 2011 to 2017 years it is less than 20% (**Figure 5.7a**). During the month of November, snow area decreases from 2010-11(42%) to 2012-13 (26%) and thereafter it increases in 2013-14 (38%) and further decreases to (34.10%) in 2017-18 and further increase upto 52.0% in 2018-19 respectively (**Figure 5.7b**). During the month of December, maximum area covered under snow goes up to 62% in 2012-13 winters, whereas the least covered are in 2011-12 (35%) and 43% in 2010-11. (**Figure 5.7c**). During the month of January, maximum area coverage could be seen is of the order of 92% during 2011-12 and the least

is of the order of 47% (2015-16) and 49.7 % (2018-19) respectively (**Figure 5.7d**), whereas during the remaining years ,it is less than 70% of the total area. Likewise in February, maximum area covered under snow is of the order of 83% (2012-13) and the least is of the order of 55% in 2015-16 and in 2017-18 respectively (**Figure 5.7e**). In the month of March, maximum area under snow could be seen in 2018-19 (79.46 %) and the minimum in 2017-18 (60.8%).

Table-5.7: Area under snow in Beas basin

Beas Basin																
Total Area- 4350 Km ²																
	2010-11	%	2011-12	%	2012-13	%	2013-14	%	2014-15	%	2015-16	%	2017-18	%	2018-19	%
Oct	1390.15	31.95	884.84	20.3	956.5	21.9	747.6	17.18	761.28	17.5	813.45	18.7	703.6	16.17	1452.6	33.39
Nov	1828.32	42.03	1293.42	29.7	1129.14	25.9	1641.77	37.7	1026.07	23.5	1576.63	36.2	1483.5	34.10	2264.76	52.06
Dec	1905.64	43.7	1546.24	35.5	2697.42	62.0	1705.15	39.1	1630.35	37.4	1592.84	36.6	2577.2	59.24	2160.02	49.66
Jan	3094.36	70.09	3984.53	91.5	2748.78	63.1	2923	67.1	2971.45	68.3	2033.74	46.7	2136.5	49.11	2164.03	49.75
Feb	2739	62.96	3468.91	79.7	3591.48	82.5	3130.2	71.9	2546.1	58.5	2405.36	55.2	2410.4	55.41	3168.3	72.83
March	2963.54	68.11	3125.72	71.8	2910.57	66.9	2902.88	66.7	3067.61	70.5	3347.43	76.9	2644.8	60.8	3456.5	79.46

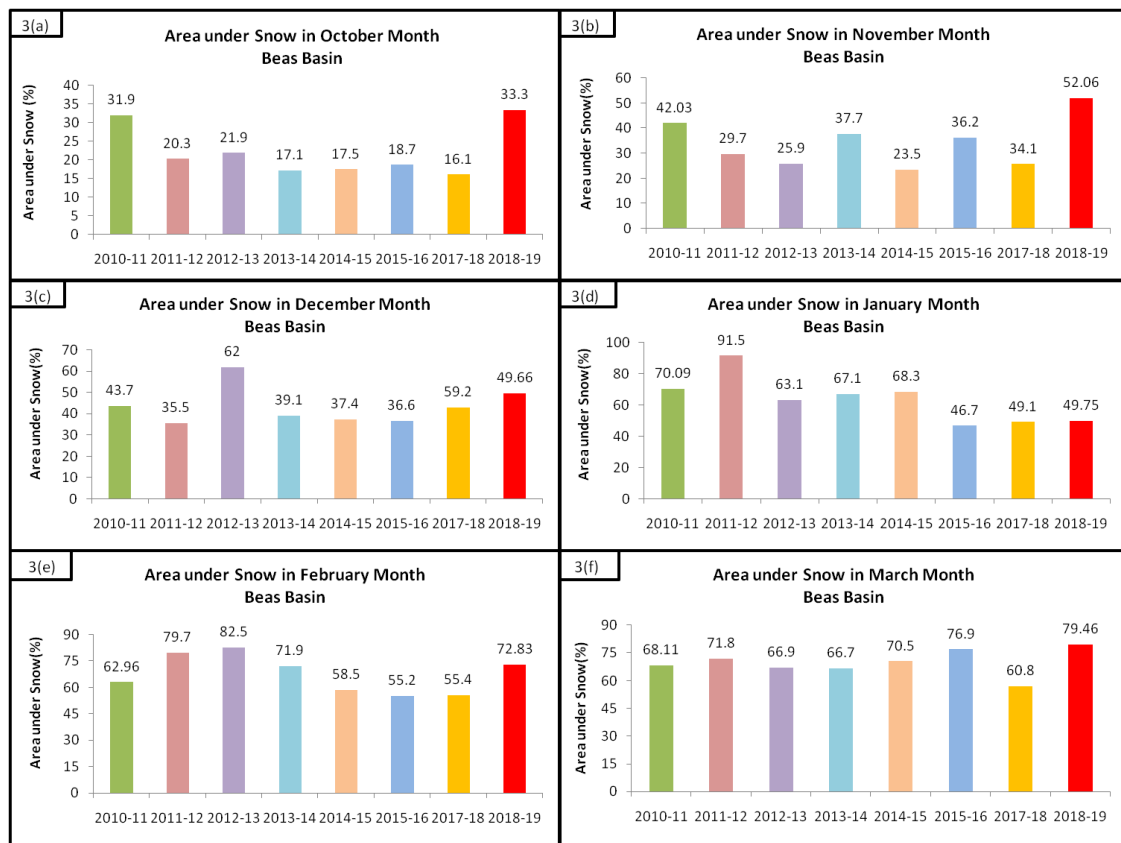


Figure 5.7: Area under snow cover in Beas Basin (a-f)

Analysis of the monthly area under snow in Satluj basin during October (2010-19) reveals a fluctuating trend in the basin with maximum area of 24% (2012-13) and the minimum as 10% during the period 2014-15, where as the in the remaining years , the area varies from 15-20% as a whole in the Satluj catchment (**Figure 5.8a**). In the month of November, the maximum area that could be observed under snow is of the order of 48 % in 2018-19, 37% (2013-14) and 34.6 in 2010-2011 whereas in the remaining years it varies from 11 to 27% respectively, minimum being 11% in 2014-15 (**Figure 5.8b**). In the month of December, maximum area covered under snow is of the order of 67% in 2012-13 followed by 57%(2014-15) , whereas in the remaining years it varies from 23 to 44% respectively (**Figure 5.8c**). During January in Satluj basin, maximum area under snow could be observed as 93% in the year 2010-11 and 90% (2013-14) , whereas in the remaining years , the area varies from 45-83% respectively (Fig.4d) Likewise in February, the area covered is more than 80 % between 2010-11 to 2018-19 , (**Figure 5.8d**). Likewise in the month of March, the values are by and large more than 85% , maximum being 95% (2012-13) and the minimum being 77.5% in 2017-18. Thus from the above analysis, it is found that winter snowfall is more towards February and March where as in the early winters i.e November-January, it is comparatively on lower side in each year.

Table-5.8: Area under Snow in Satluj

Satluj Basin																
Total Area-11634 Km ²																
	2010-11	%	2011-12	%	2012-13	%	2013-14	%	2014-15	%	2015-16	%	2017-18	%	2018-19	%
Oct	4406.01	37.8	1861.62	16.0	2834.22	24.3	2127.58	18.2	1109.69	9.5	2336	20.0	1480.3	12.7	4222.4	36.29
Nov	4034.66	34.6	1337.94	11.5	2614.57	22.4	4305.04	37.0	1276.44	10.9	3163.1	27.1	3177.8	27.3	5569.59	47.87
Dec	4754.2	40.8	2646.07	22.7	7831.31	67.3	3521.17	30.2	6605.3	56.7	3592.2	30.8	7177.0	61.6	7108.75	61.10
Jan	10766.66	92.5	7239.68	62.2	8604.56	73.9	10458.6	89.8	9674.69	83.1	5238.8	45.0	8583.2	73.7	8578.08	73.73
Feb	9954.6	85.5	10888.96	93.5	11240.6	96.6	10080.37	86.6	8880.48	76.3	9392.33	80.7	9516.5	81.7	10940.7	94.04
March	9786.79	84.1	10733.85	92.2	11066.03	95.1	10353.6	88.9	9931.02	85.3	10265.5	88.2	9022.5	77.5	10662.87	91.65

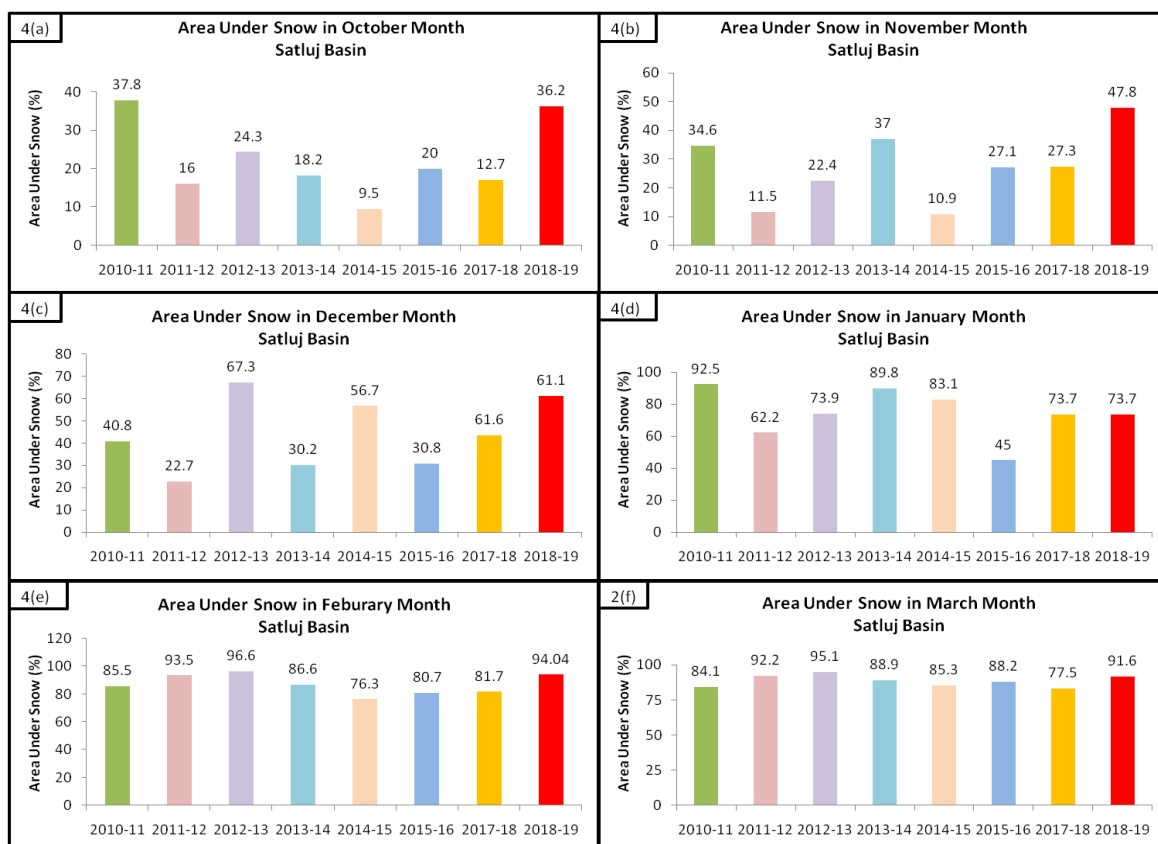


Figure 5.8: Area under snow cover in Satluj Basin

Thus based on the above analysis, it is concluded that during 2018-19 there is considerably increased snowfall in Himachal Himalaya. Total spatial distribution area of snow in Ravi basin which is on south of Pir Panjal range shows the good amount of snowfall in the year 2018-19. Area under snow in Ravi basin was mapped as 14139.95 km² in 2018-19 which was mapped 9142.44 km² in 2017-18 and shows overall increase by about 54.6% in 2018-19. In Chenab basin an increase of about 23.2% (2018-19) has been observed. The area under snow in 2017-18 was mapped as 37616.42 km² in 2017-18 shown in **(Figure 5.9)**. Likewise Beas Basin shows an increase of about 22.6% in comparison to 2017-18. In Beas Basin surface area has increased from 11956 km² (2017-18) to 14666.21 km² in (2018-19). . On the South eastern part of the state i.e. along satluj basin, the basins viz. Baspa, Spiti, Pin are showing the similar trend of having maximum area under snow in 2018-19 Satluj basin also shows increased surface area from 38957.31 km² to 47082.39 km² in 2018-19 shows an overall increase of 20.8% (2018-19) **(Figure 5.9)**. On analyzing satellite data it is found that total area under snow in Himachal Pradesh has been increased by about 25.16 % in

2018-19 in comparison to the total monthly averaged area in Himachal Pradesh 2017-18 (Table 5.9 & Figure 5.10).

Table 5.9: Area under Snow in Himachal Pradesh

Basin wise Snow Cover in H.P			
Basin	2017-18	2018-19	% Change
Ravi	9142.44	14139.95	54.6
Beas	11956	14666.21	22.6
Satluj	38957.31	47082.39	20.8
Chenab	37616.42	46358.36	23.2
Total	97672.17	122246.9	25.16

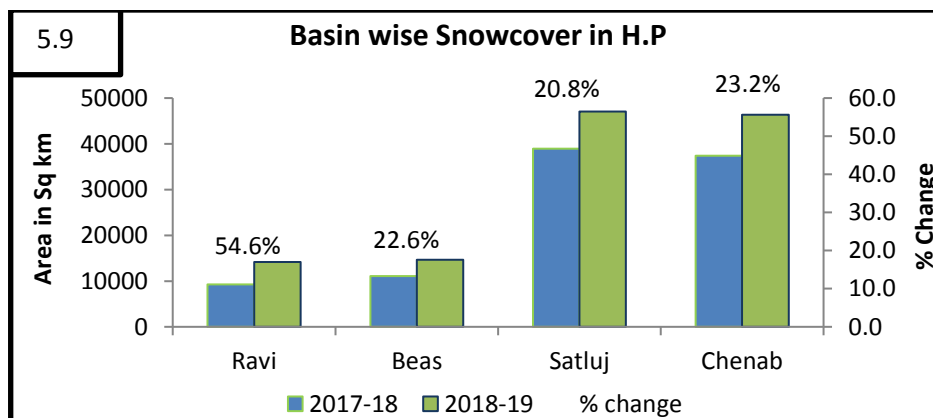


Figure 5.9: Basin wise snow cover in H.P

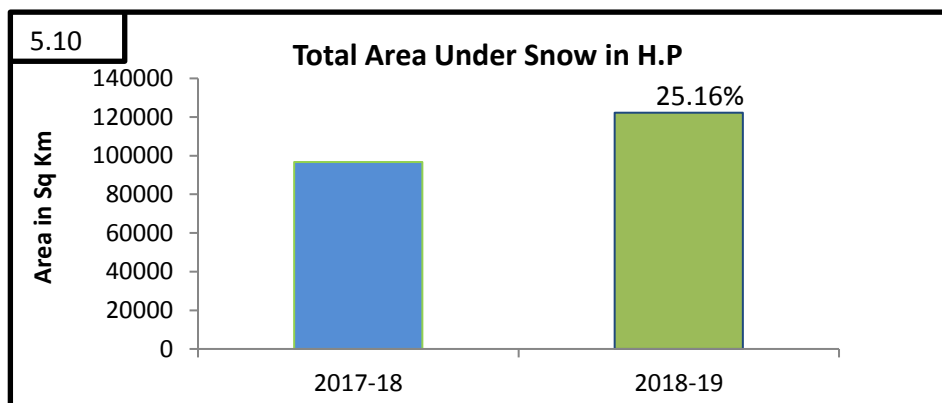


Figure 5.10: Total Area Under Snow in H.P

6. Concluding Remarks:

- The analysis has been made from the AWiFS satellite data for 2018-19 for assessing the total area under snow cover during the period October to March and its temporal analysis with that of the monthly averaged values of the total area under snow 2017-18, the following inferences are drawn:
- Basin wise analysis from October to March in 2018-19 and its comparative analysis with that of 2017-18 reveals that, in Chenab basin, maximum increase is of the order of about 183.2% in the month of October, where as November shows an increase of about 45.1% and December, January shows an increase of about 17.4% and 4.2% respectively and February, March shows about 7.2% and 5.3% increase in comparison to 2017-18.
- Ravi basin shows overall increase of about 411.2% in October, while in November it shows an increase of about 93% in 2018-19 whereas January, February and March shows 38.3%, 96.1% and 51.2% respectively, In December, total snow cover has decreased by 11.4% (2018-19) in comparison to 2017-18.
- Beas basin also shows a more or less similar trend of increase in October by about 106.45%, whereas November, February and March shows of 52.66%, 31.46%, 30.69% respectively in 2018-19, and there is reduction of 16.18 % in the month of December (2018-19).
- In Satluj basin it is concluded that during 2018-19 there is considerably increased snowfall in October (185.2%) and November (75.2%). Whereas December and January months showing reduction of 0.95% and 0.05%. and the increase of the order of 14.9% and 18.1% respectively in February and March.
- Similarly month wise(October-March) yearly (2010-18) plotting of total area under snow cover in different basins reveals that by an large all the basins, there is less area under snow in the months of October to December each year, whereas the snow cover increases in January to March with more area in February and March . Also from the year 2014-15 onwards, slight reduction in the snow cover area has also been observed in all the winter months. The study revealed that the month of October (2018-19) witnessed the increase in snow cover first time after a long span of eight years. Plotting of total area under snow (2018-19) in Himachal Pradesh there is considerably increased snowfall in

Himachal Himalaya and its comparative analysis with that of area in 2017-18 during the months (Oct-March), reveals that Ravi basins shows highest increase in area with 54.6% (2018-19) in comparison to 2017-18, whereas Beas, Satluj and Chenab also witnessed increase that is 22.6%, 20.8% and 23.2 % respectively.

- As a whole total increase of 25.16% in the area under snow cover has been observed in Himachal Pradesh in 2018-19 in comparison to the total area during 2017-18.
- Based on the satellite data It has been observed that by and large all the basins shows an increased percentage change in their area under snow reflecting that 2018-19 is the year of exceptionally heavy snowfall in all the basins of Himachal Pradesh.

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