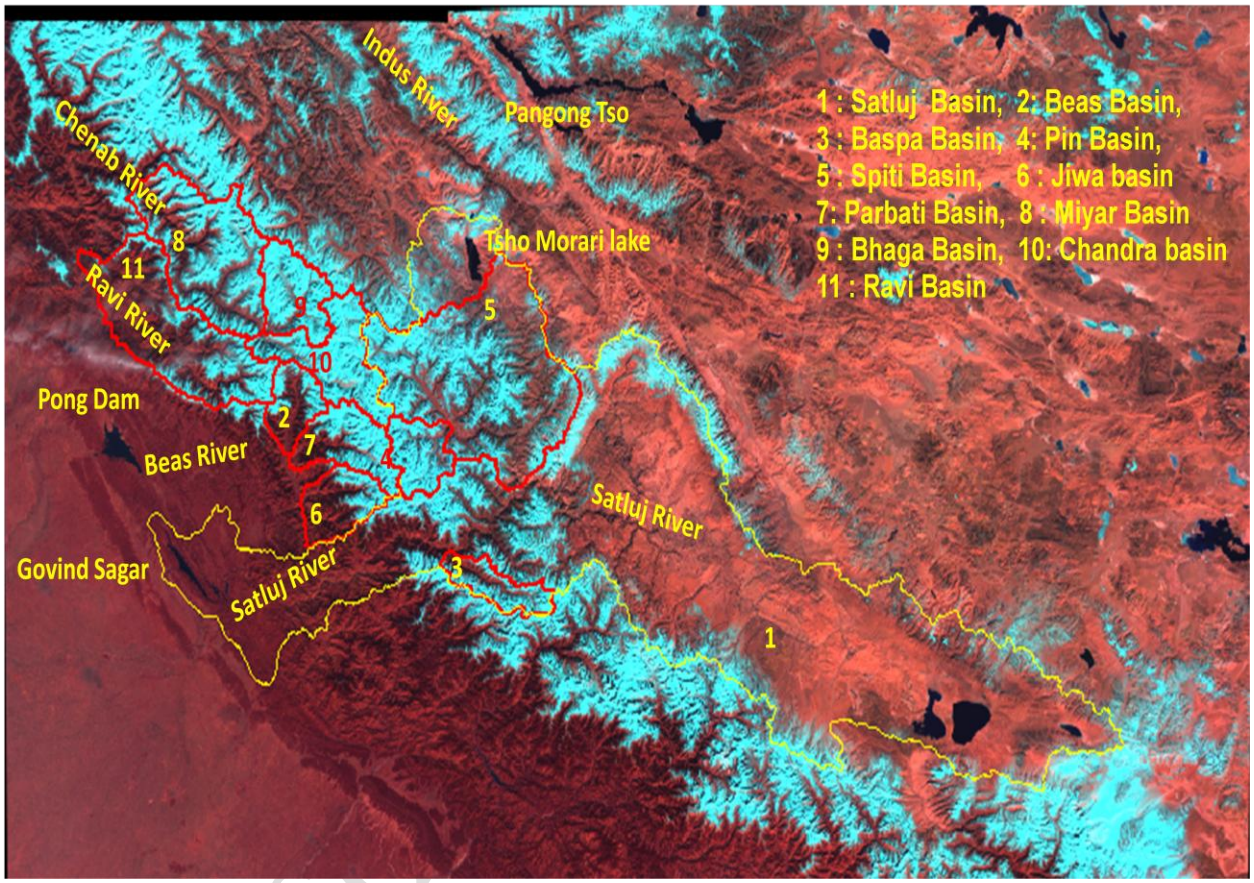
ASSESSMENT OF SEASONAL SNOW COVER VARIATION DURING THE YEAR 2015-16 IN HIMACHAL PRADESH USING SPACE DATA



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Title	**Monitoring of Seasonal Snow Cover in Himachal Pradesh using satellite data.**
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Abstract	**The state of Himachal Pradesh, receives winter precipitation in the form of snow in the higher altitudes during the months of October to March. About 1/3rd of the total geographical area remains under thick snow cover during the winter season. Most of the major rivers and the perennial streams originating from the Himalayas depend upon the seasonal snow cover for their discharge dependability. As part of the climate change impact studies on the Himalayan region, an attempt has been made to map the seasonal snow cover distribution in Chandra, Bhaga, Miyar Pin, Spiti, Baspa, Jiwa,Baspa,Parbati and Beas sub basins in Himachal Himalaya during the year 2015-16. In order to assess the changes in the snow cover extents, the results thus obtained were compare with that of the results obtained for seasonal snow cover during 2010-14 and the monthly averaged values have been used to assess the changes during 2010-14 with that of the period 2015-16. Based on the observations, it has been found that there si reduction in the snow cover area in almost all the basins in Himachal Himalayan during 2015-16 in comparison to 2010-14.**
Key words	
Security classification	**Unrestricted**

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Introduction:

Snow covers almost 40 per cent of the Earth's land surface during Northern Hemisphere winter. 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

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).

Background:

The state of Himachal Pradesh, receives winter precipitation in the form of snow in the higher altitudes during the months of October to March.. About 1/3rd of the total geographical area remains under thick snow cover during the winter season. Most of the major rivers and the perennial streams originating from the Himalayas depend upon the seasonal snow cover for their discharge dependability. The three broad divisions Himalayan region(Lower, Middle and Upper) receives average snowfall (1990-2004) of 1178cm, 537 cm and 511cm respectively (Sharma et al 2000, Gusain et al, 2004). As per one of the studies carried out by SAC Ahmedabad in the Ravi and Bhaga basins reveals some interesting results. These two basins are important because of the fact these are on the either side of the Pir Panjal Range i.e. Ravi basin lies on the south and the Bhaga basins lies on the north of Pir Panjal Range and Pir Panjal range has the orographic control on the accumulation and snow fall pattern in the region. The area altitude distributions of these basins have shown that Ravi basin is located in lower altitude zone. For example, 90% area of the Ravi basin is located at an altitude below 4000m, where as in Bhaga basin it is only 20%. Altitudes of the Ravi and Bhaga basins range from 630 m to 5860m and from 2860m to 6352m respectively. In Ravi basin, snow accumulation and ablation are the continuous process throughout the winter. Even in the middle of winter, melting of large snow cover area was observed. Similar trends were observed for the year 2005-06 and 2007-08(Figure1) which shows a

significant reduction in snow cover extent during the winter season. During summer season, snow ablation was fast and almost 50% of the snow cover was melted within a period of one month and by the end of June almost 80% of snow cover was melted. In Bhaga basin, snow melting was observed in the early part of the winter i.e. in the month of December Snowpack was stable from the middle of January to the end of April .This observation is consistent with earlier observations made in Baspa basin (Kulkarni and Rathore,2003). Baspa is a high altitude basin and is located on the Northern side of the Pir Panjal Range. In this basin, significant melting of snow was observed in December influencing stream run off. These observations suggest that river basins are responding to climate change depending on geographical location and altitude distribution.

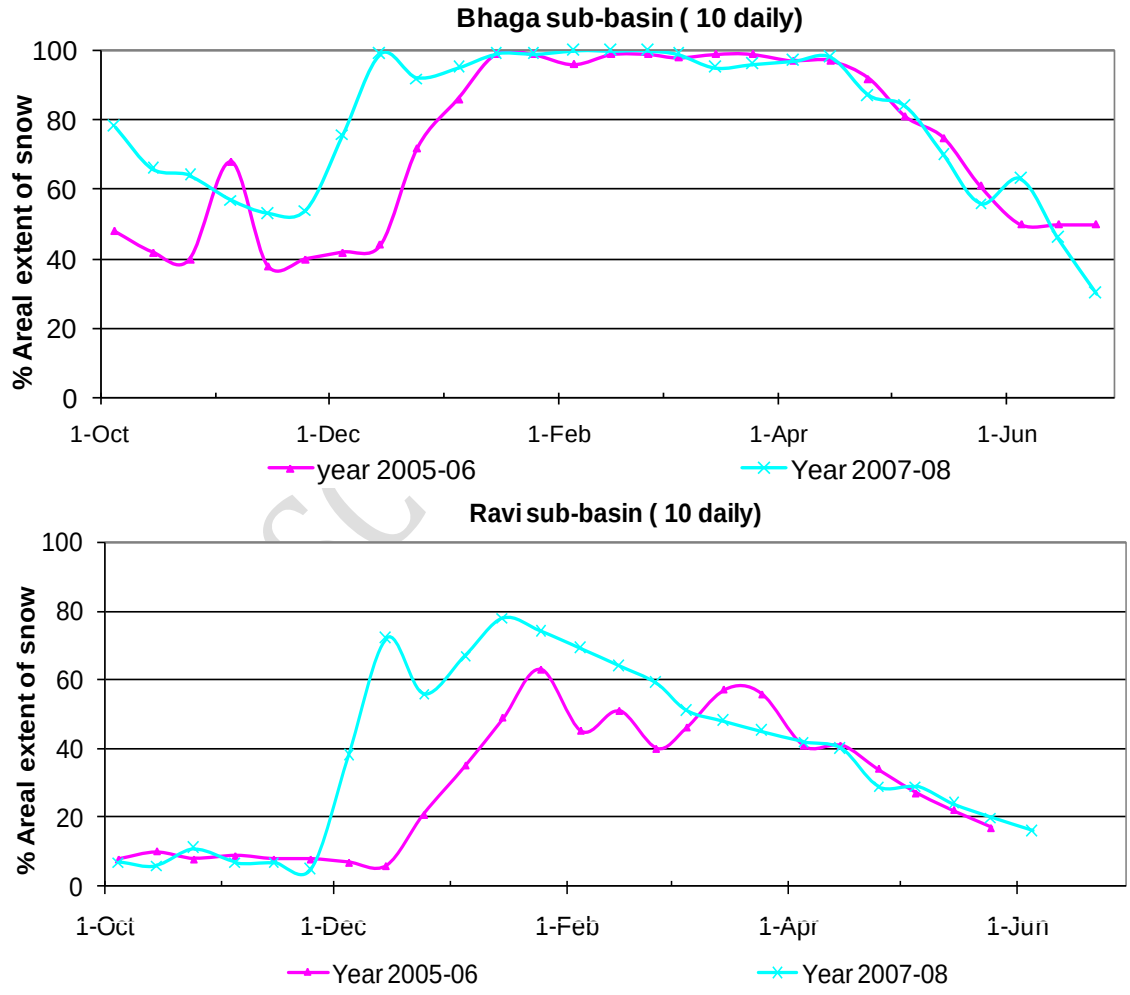


Figure 1: Accumulation and ablation pattern of snow during 2005-06 & 2007-08

Study Area:

The study area comprises of distribution of snow cover in Chandra, Bhaga, Miyar Pin, Spiti, Baspa, Jiwa,Baspa,Parbati and Beas sub basins in Himachal Himalaya as per Fig.2.

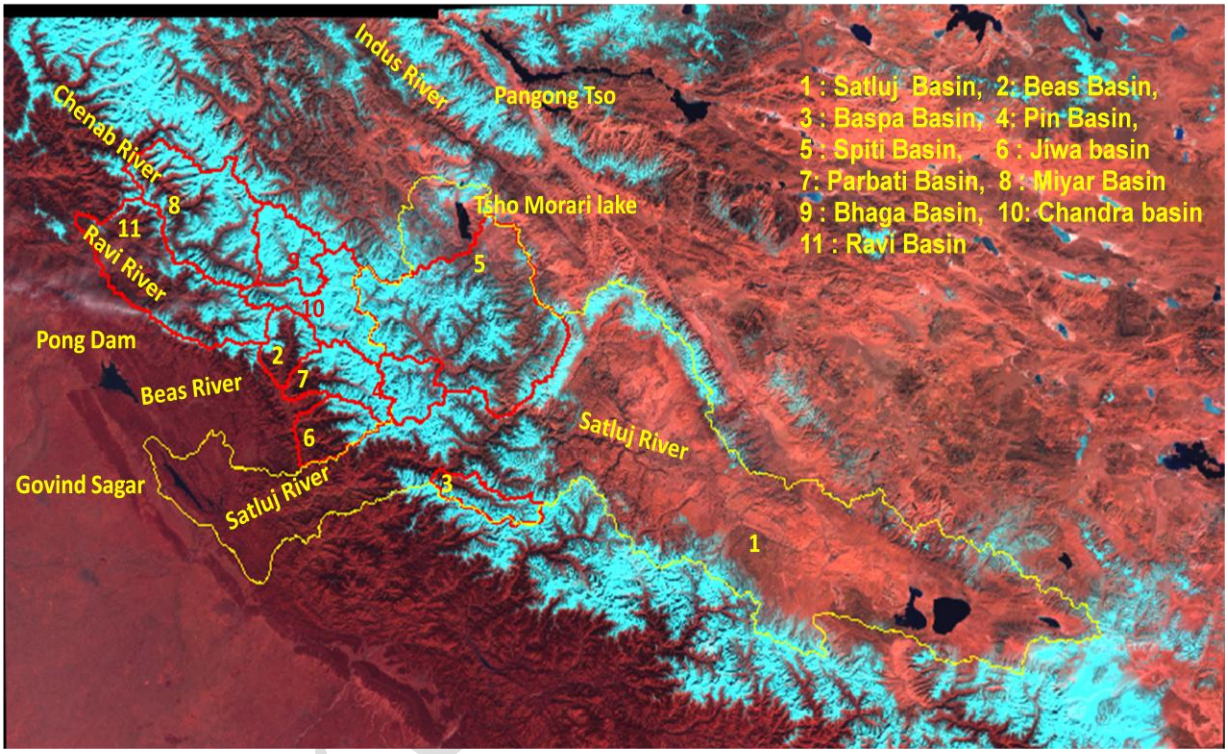


Figure 2 : Location of sub-basins at Himachal Pradesh

Data used:

AWiFS data from October 2015 to April 2016 was used in this study.

Methodology:

Normalised 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) utilize 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:

$$Normalized\,Difference\,Snow\,Index(NDSI) = (band2 - band5)/(band2 + band5) \quad ..(1)$$

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. 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 and 10-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. In 10-daily product, three scenes are analyzed, if available. For example, 10 March product data of 5, 10 and 15 March was used. If any pixel is identified as snow on any one date then this pixel will be classified as snow on final product. This provides snow cover at an interval of 10 days, an important requirement in hydrological applications. Therefore, this product is generated basin-wise. Since this product is using three scenes, probability becomes high that at least in one scene, pixel may be cloud-free and this helps in overcoming problem associated with snow under cloud cover. If three consecutive scenes are not available, then all available scenes in 10 days window was used in the analysis. Differentiation between water and snow is difficult using NDSI image. In addition, separation of snow and water pixels is also difficult based on reflectance due to mountain shadow. Therefore, in the present algorithm, water bodies are marked in pre-winter season and are masked in the final products during winter.

Results and discussions

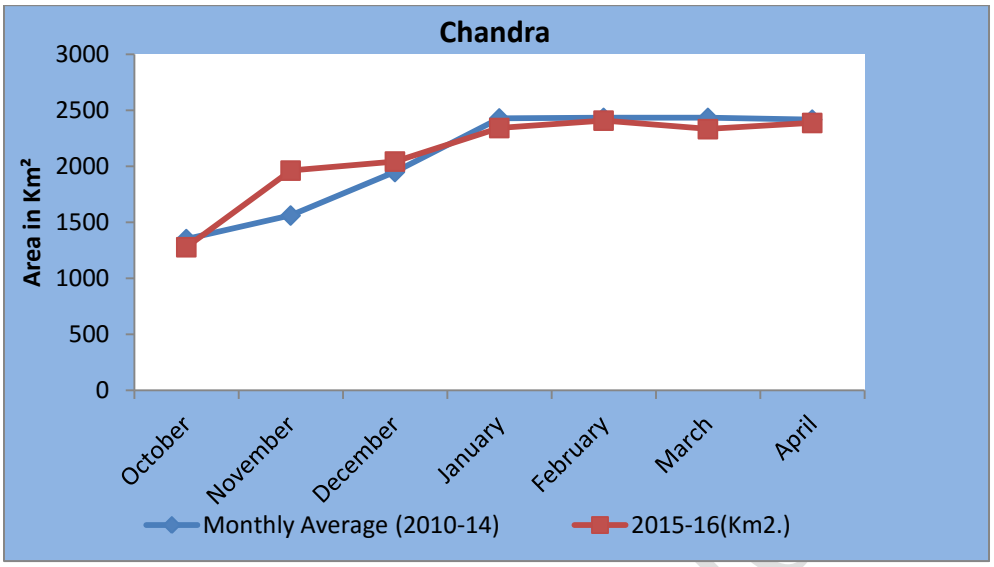
Considering the present trend of winter snowfall in Himachal Pradesh during 2015-16, the winter precipitation was observed in all the basins viz Chandra, Bhaga, Miyar, Beas, Parvati, Jiwa, Pin, Spiti and Baspa during 2015-16 was estimated and analyzed with reference to the averaged value of the total area under snow cover during the months of October to March for the period 2010-14. From the analysis, it has been found that the basins i.e. Chandra, Bhaga and Miyar which are locating on the north of the Pir Panjal Range behaves differently than the southern basins in having the winter precipitation. This is mainly due to the fact that the Pir Panjal Range has orographic control and by virtue of its location, the western disturbances arising out of the westerly originating mainly from the Mediterranean sea and then entering India through Pakistan, Afghanistan, Iraq and Iran, and the northern basins being close receive more winter accumulations than the basins on the southern side of the Pir Panjal Range.

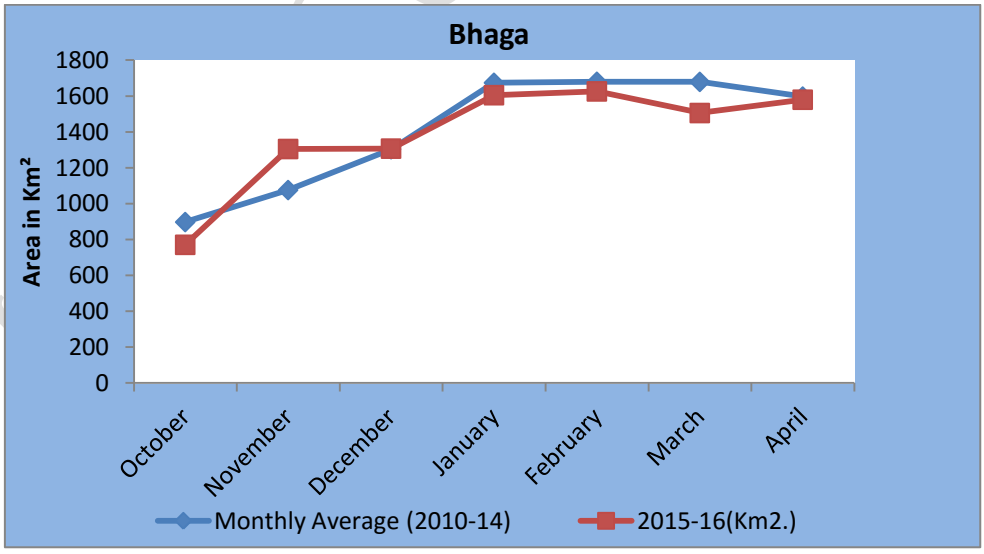
Based on the satellite data analysis and the statistics thus observed for the 2015-16, it has been found that the basins (Chandra,Bhaga abd Miyar) which are located on the north of Pir Panjal Range have almost similar trends of having area under snow cover during the period October to March. During the month of October , Chandra basin shows a reduction in the snow cover area by about 5% where as the in November, this basins shows an increase in its area under snow by about 25% as observed during the period 2010-14. During the peak winter months (December – February) an increase of about 5% has been observed during December whereas during the other peak winter months, it shows a reduction in its under snow by about 3% and 1% respectively. During March this basins also shows similar trend of reduction in its area by about 4% in its area under snow cover in comparison to the area as observed during 2010-14. Likewise the adjoining basin i.e. the Bhaga basin in this part also shows a similar trend i.e. about 14% reduction in the month of October and about 21% increase in the month of November and a very slight increase by about 0.2% in the month of December in comparison to its area during the period 2010-14. The other peak winter months i.e January and February shows reduction in the snow cover area by

about 4% and 3% respectively where as during March a reduction of about 10% has been sobered in this region in its area under snow cover. The Miyar basin which is on the northeastern side of the Pir Panjal Range also shows similar results i.e. during October more reduction has been observed in this basin in comparison to other two basins in this part (Chandra and Bhaga) which is about 21% less than the snow cover area as observed in 2010-14, where as in November, it shows an increase by about 40%. Further during peak winter months, it shows a very small increase by about 3% in December where as the other two peak months, the snow cover has been reduced by about 14% and 18% respectively in comparison to the period 2010-14. Similarly in March the snow cover has been reduced by about 26% in this basin. Thus the basins on the north of Pir Panjal Range shows an increase in the snow covered area in November and December whereas lesser winter precipitation in October and the peak winter month January, February and late winters (March) in 2015-16 in comparison to the total area under snow in 2010-14(Fig 3a,b,c) and Table 1.

Table 1: Area under Snow in Chandra, Bhaga and Miyar basins

Name of the Basin	Observation Month	Area under Snow (Monthly Average) (2010-14) Sq km	Area under Snow (Sq km) 2015-16	Difference in area under snow cover
Chandra	October	1352	1279	(-)5%
	November	1562	1963	(+)25%
	December	1950	2044	(+)4%
	January	2428	2343	(-)3%
	February	2433	2433	(-)1%
	March	2433	2433	(-)4%
	April	2418	2388	(-)1%
Bhaga	October	898	771	(-)14%
	November	1076	1305	(+)21%
	December	1304	1307	(+)0.2%
	January	1674	1605	(-)4%
	February	1680	1626	(-)3%
	March	1680	1506	(-)10%
	April	1598	1580	(-)1%
Miyar	October	1427	1107	(-)22%
	November	2109	2947	(+)39%
	December	2669	2762	(+)3%
	January	4206	3359	(-)20%
	February	4401	3608	(-)18%
	March	4283	3164	(-)26%
	April	3931.36	3465.52	(-)11%


Chandra
3000
2500
2000
1500
1000
500
0
Area in Km²
October
November
December
January
February
March
April
Monthly Average (2010-14)
2015-16(Km2.)


Bhaga
1800
1600
1400
1200
1000
800
600
400
200
0
Area in Km²
October
November
December
January
February
March
April
Monthly Average (2010-14)
2015-16(Km2.)

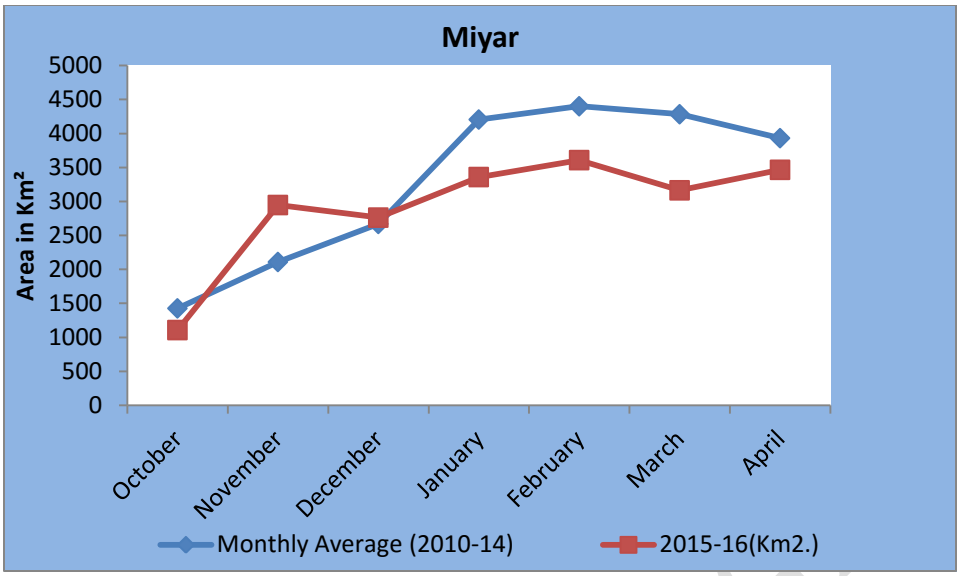


Fig 3 a,b,c

Further on the south of Pir Panjal Range in the Ravi basin, similar trend of less snowfall has been observed during 2015-16 in comparison to the averaged value of area under snow during the period 2010-14. In Ravi basin, a positive trend has been observed during November 2015 which indicates an increase of about 30% in the snow cover area in comparison to the period 2010-14, whereas in October a decreasing trend has been observed. The peak winter months (Dec-Feb) and the late winter or early summer month March shows comparatively more reduction in the snow cover area in this basin which is by about 37%,48% 48% and 38% respectively in comparison to the period 2010-14(Fig4) & Table 2.

Table2: Area under Snow in Ravi Basin

Name of the Basin	Observation Month	Area under Snow (Monthly Average) (2010-14) Sq.Km.	Area under Snow (Sq.Km.) 2015-16	Difference in area under snow cover
Ravi	October	703.2175	367.55	(-)47%
	November	836.7275	1092.28	(+)30%
	December	1811.438	1138.54	(-)37%
	January	3399.06	1702.36	(-)38%
	February	3494.508	1805.85	(-)48%
	March	2859.005	1757	(-)38%
	April	2185.57	1717.73	(-)21%

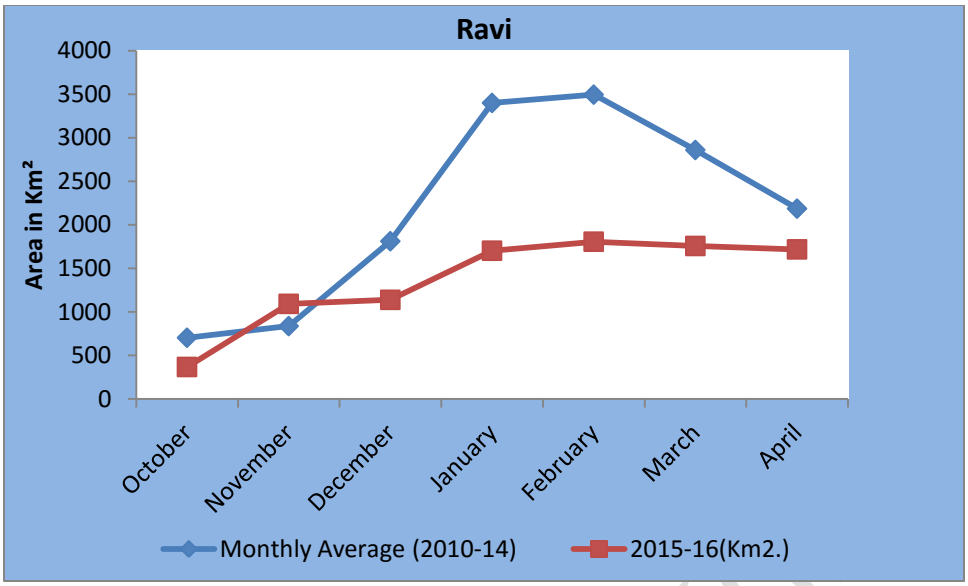
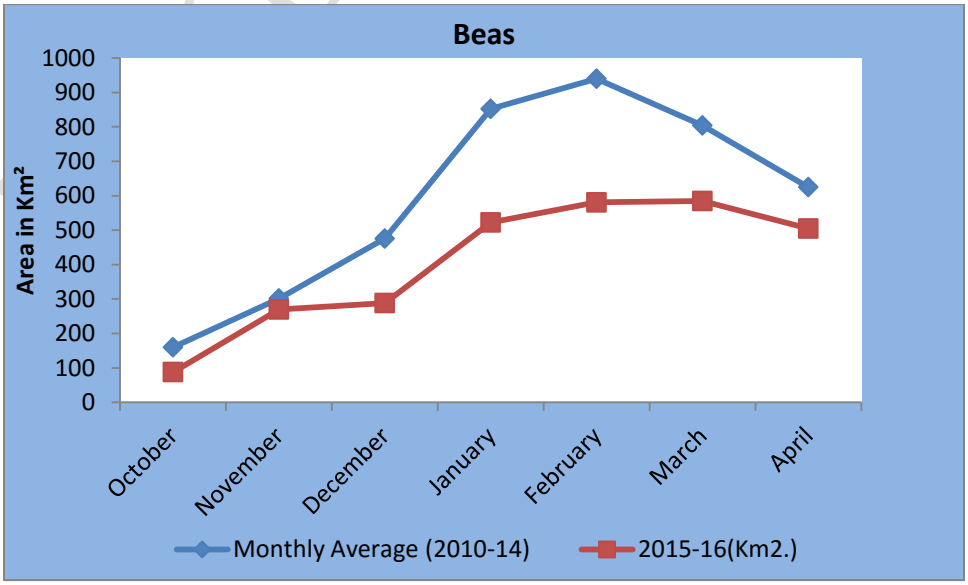


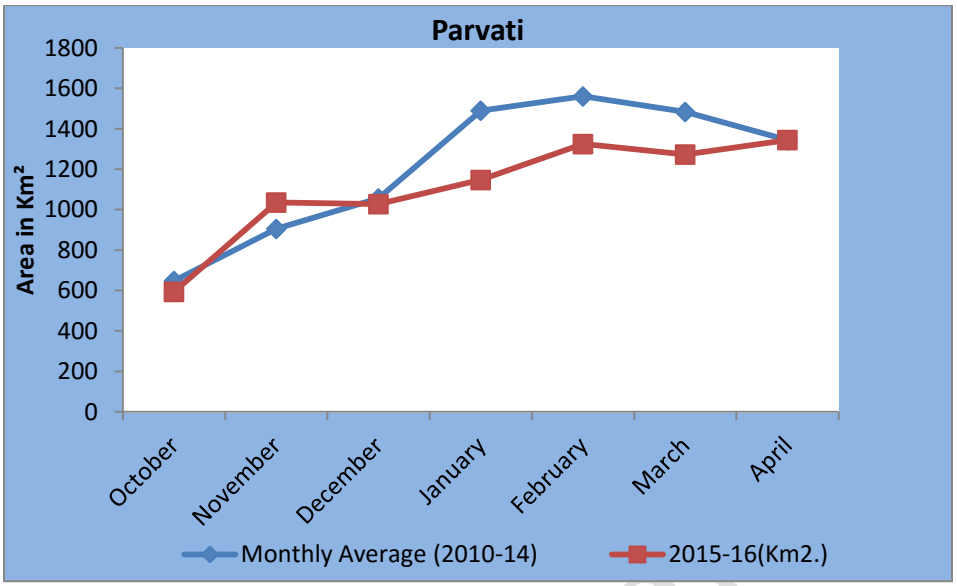
Fig.4

Likewise the Beas basin which includes two other sub basins viz. the Parvati and Jiwa basins also falls on is on the southern side of the Pir Panjal Range and shows similar trends of lesser snowfall during 2015-16 in comparison to the period 2010-14. The uppermost part the Beas basin i.e the area on the upstream side comprising the upper Beas basin shows negative trends during 2015-16 indicating all the a decrease in area under snow in all the months of observation by about 45%, 10%, 39%, 39%, 38% and 27% respectively in comparison the areas under snow cover during 2010-14 (Fig5a).The areas on further south i.e along Parvati and Jiwa sub basins, the snow cover during October, December, January, February and March shows reduction in the area by about 8%, 2%, 20%, 15%,and 14% in Parvati basin except an increase by about 14% in the month of November 2015 in comparison to 2010-14 period. Likewise the Jiwa basin also shows similar results i.e an increase of about 1% in November whereas October, December, January, February and March shows a reduction of about 30%, 36%, 55%,44% and 29% respectively(Fig5b&c). Thus by and large the Beas basin as a whole shows less snow fall in the area including the lower catchments of the Beas basin i.e Parbati basin and Jiwa basin which shows similar trends in October, December and January with a small variation observed in November in comparison to the total areas as observed in 2010-14 (Fig.3a,b,c) & Table 3.

Table 3: Area under Snow in Beas, Parvati & Jiwa basins

Name of the Basin	Observation Month	Area under Snow (Monthly Average) (2010-14) Sq.Km.	Area under SNow (Sq.Km.) 2015-16	Difference in area under snow cover
Beas	October	159.8675	87.9	(-)45%
	November	301.6275	269.65	(-)10%
	December	475.625	288.31	(-)39%
	January	852.38	522.48	(-)38%
	February	939.8733	580.69	(-)38%
	March	804.23	584.76	(-)27%
	April	625.18	504.73	(-)19%
Parvati	October	647.78	593.71	(-)8%
	November	904.9225	1035.81	(+)14%
	December	1056.21	1027.91	(-)2%
	January	1490.235	1147.3	(-)23%
	February	1560.703	1324.94	(-)15%
	March	1483.688	1273.29	(-)14%
	April	1343.71	1344.94	(+).09%
Jiwa	October	187.3525	131.84	(-)29%
	November	266.6125	271.17	(+)1%
	December	431.7775	276.62	(-)35%
	January	845.0525	363.96	(-)56%
	February	896.1667	499.73	(-)44%
	March	687.76	489.38	(-)28%
	April	539.7	573.21	(+)6%





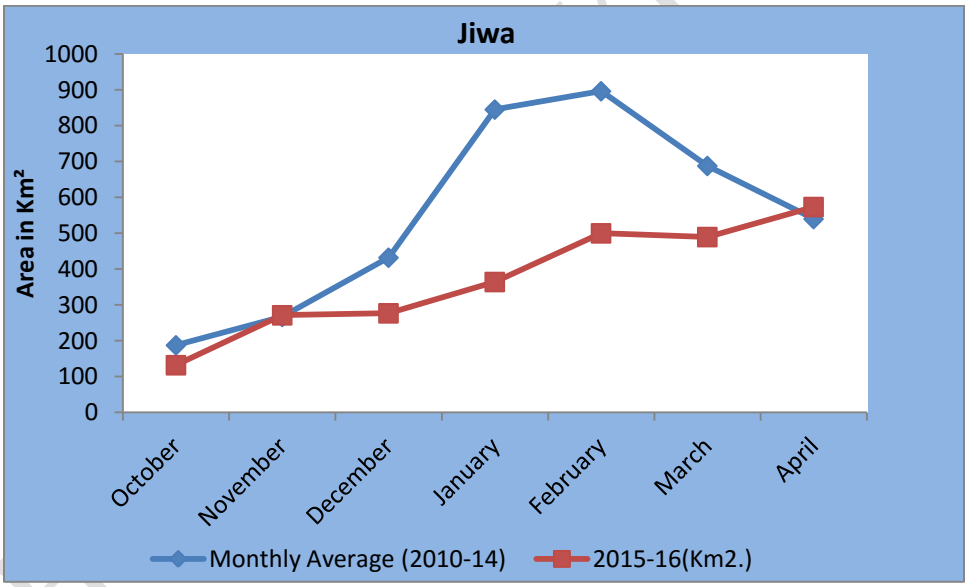


Fig.5a,b,c

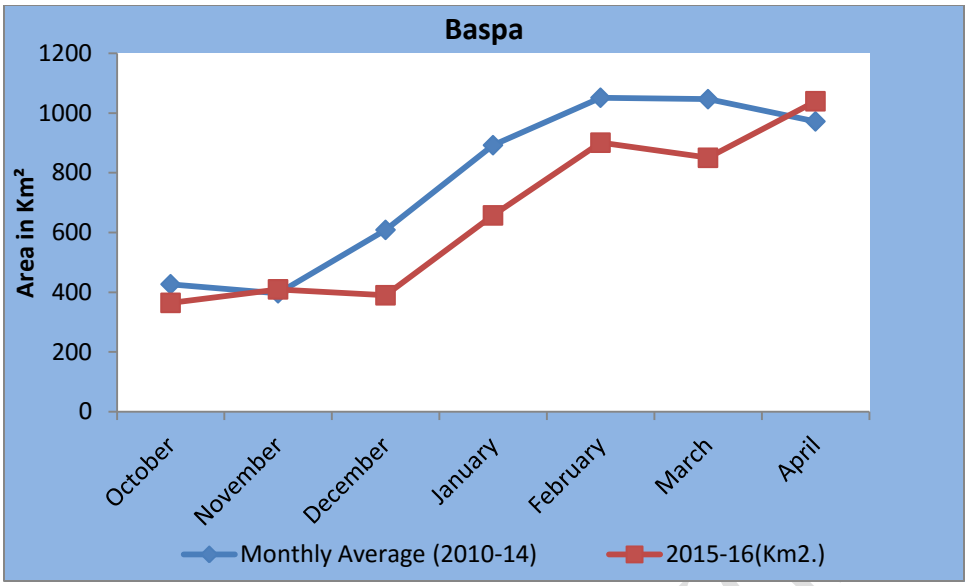
On the southeastern part of the state in Satluj basin, the analysis was carried out for Baspa, Pin and Spiti sub basins respectively. The Baspa basin which is on the lower reaches reveals a reduction in the snow cover area by about 15%,36% , 23% ,14% and 19% respectively 2015-16 during the months of October, December, January, February and March whereas the November months shows an increase in its snow cover area by about 3% in 2015-16 in comparison to the previous trends(Fig 6a).

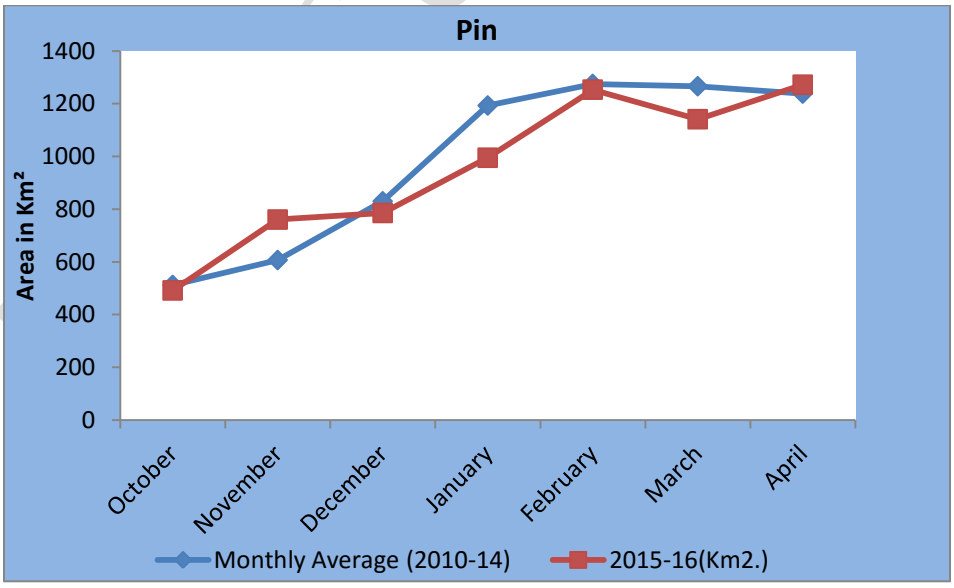
On the higher reaches, the Pin basin also shows similar results but the observed values are comparatively better than the Baspa basin.(Fig6b) shows that October, December, January, February and March in Pin basin, the snow cover has been reduced by about 4%,5%,16%,2% and 10% respectively in comparison to the snow cover as observed on 2010-14, where as in November an increase of about 25% has been observed in this basin.

Likewise the Spiti sub basins which is an adjoining basin to the Spiti basin, shows slightly change in trends i.e in March a slight increase by about 1% has been observed in this basin ,whereas during October to February , this basin decrease in its area under snow by about 14%,4%,26%,50% and 12% respectably in 2015-16 in comparison to the area during 2010-14(Fig6c) & Table 4.

Table 4: Area under Snow in Baspa, Pin & Siiti basins

Name of the Basin	Observation Month	Area under Snow (Monthly Average) (2010-14) Sq.Km.	Area under Snow (Sq.Km.) 2015-16	Difference in area under snow cover
Baspa	October	427	364	(-)14%
	November	396	410	(+)3%
	December	609	390	(-)35%
	January	892	657	(-)26%
	February	1051	901	(-)14%
	March	1046	850	(-)18%
	April	972	1039	(+)6%
Pin	October	512	492	(-)4%
	November	607	760	(+)25%
	December	830	785	(-)5%
	January	1193	995	(-)16%
	February	1275	1253	(-)1%
	March	1266	1141	(-)9%
	April	1238	1272	(+)2%
Spiti	October	1722	1481	(-)13%
	November	2070	1993	(-)3%
	December	3247	2417	(-)25%
	January	7182	3587	(-)50%
	February	8215	7239	(-)11%
	March	8173	8274	(+)1%
	April	6741	7464	(+)10%


Baspa
1200
1000
800
600
400
200
0
Area in Km²
October
November
December
January
February
March
April
Monthly Average (2010-14)
2015-16(Km2.)


Pin
1400
1200
1000
800
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Area in Km²
October
November
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March
April
Monthly Average (2010-14)
2015-16(Km2.)

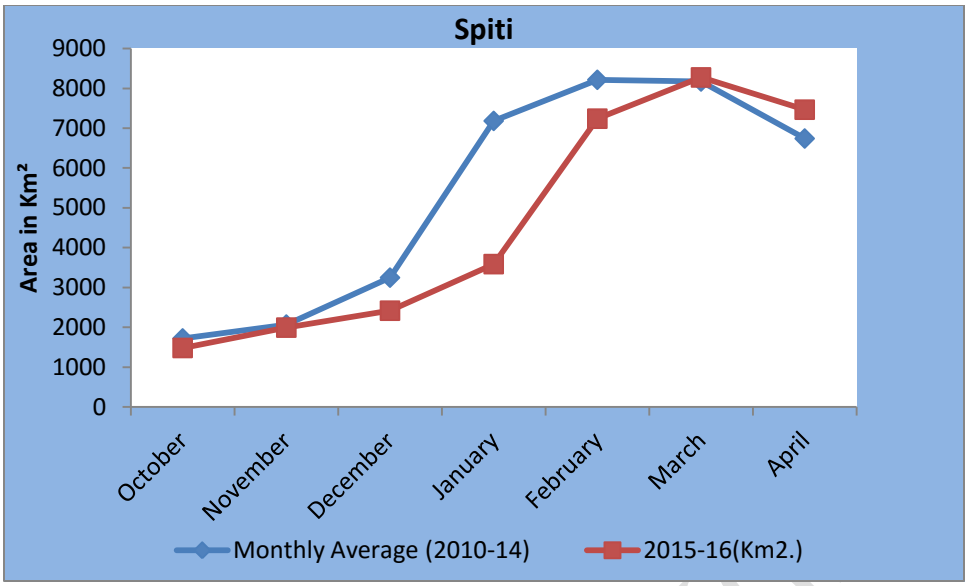

Fig.6a,b,c

Concluding Remarks:

Based on the satellite data interpretation and the analysis carried out for the year 2015-16 for mapping area under seasonal snow cover using AWIFS satellite data in Himachal Pradesh covering all the basins viz., Chandra,Bhaga, Miyar, Beas,Parvati, Jiwa, Baspa, Pin and Spiti sub basins, it has been found that by and large all the basins shows a decrease in their area under snow cover in comparison to the averaged value of area under snow during the period 2010-14. The basins which are on the northern side of the Pir Panjal Range shows comparatively better results than the southern basins, but the overall area under snow during peak winter months in these basins is also less than the previous years (2010-14).The Ravi basin which is on the southern side of the Pir Panjal Range also shows less snowfall area during 2015-16 and comparatively the values are quite prominent in all the months except November wherein it shows a positive correlation. Likewise the Beas basin which includes Parvati and Jiwa basins shows less area under snow in all the winter months except a small variation in the Parvati basin which shows a positive trend in the month of November. The uppermost part of Beas basin i.e the areas on the upstream of Bhuntar shows negative results in all the observation months (Oct to March) in 2015-16 in comparison to the area as in 2010-14, whereas there is slightly better results in Parbati basins which

may be due to altitudinal effects. The Jiwa basins which is on the lower elevations also shows less area under snow cover during 2015-16 in comparison to its area under snow in 2010-14. On the southeastern part of the State i.e along the Satluj basin, the basins viz. Baspa, Spiti and Pin also shows similar results of having less area under snow in 2015-16 than the previous years. The Baspa basin which is on the lower elevations shows comparatively less area under snow than the Pin and Spiti basins which are on higher elevations in this part of the study area. The Baspa basin except November shows a very marginal increase whereas the other months of observations i.e Oct, Dec, Jan, Feb and March shows reducing trends in their area under snow fall but comparatively better than the Beas and Ravi basins. The Pin basins in this part also shows reducing trends of snowfall in all the months except the November where in it shows an increasing trend. The Spiti basins which is an adjoining basin to the Pin , also shows negative trends of snowfall in all the month except a marginal increase of 1% during March in comparison to the previous years of observations. Thus based on the above observations, it is concluded that during 2015-16 there is considerably less snowfall in Himachal Himalaya, the effects of which can be seen more effectively in the Beas, Parvati,Jiwa and Ravi basins which are on the southern side of the Pir Panjal Range. The basins which are on the north of Pir Panjal Range and on the southeastern part of the state are also characterized by less snowfall during this period but are slightly better than the Beas and Ravi basins in Himachal Pradesh.

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