Monitoring and Analysis of North-West Himalayan Snow Cover using Optical Satellite Data and In-Situ Observations

Surbhi Garg†, Kamal Kant Singh‡, Balraj Singh Sidhu† and V. D. Mishra‡
†PTU GZS Campus Bathinda, Punjab, 151 001, India
‡ Snow and Avalanche Study Establishment (SASE), Chandigarh 160 036, India

Abstract: **Most of the part of North-Western (NW) Himalaya remains snow covered during winter season and the amount of snow plays important role in hydrological and climate related studies of the region. However, due to the rugged terrain of Himalaya it is very difficult to collect the snow cover data by manual methods in peak winter. Remote sensing based techniques have the potential to capture the data with high temporal and spatial resolution. In this paper data of AWiFS and AWiFS-II sensors in IRS-P6 satellite has been used for the study. Normalized Difference Snow Index (NDSI) is used for the estimation of snow in the different basins of the NW Himalaya. Snow cover maps have been generated and from the study it has been observed that snow covered area (SCA) in Pahalgam, Gulmarg and Sind is higher in comparison to Banihal and Uri sub-basins of NW Himalaya. After analyzing 9 years satellite data the trends in SCA have been plotted and those were further analyzed using the metrological data.**

Keywords: Snow cover monitoring, AWiFS, SCA, NW-Himalaya.

1. INTRODUCTION

Snow an important component of the cryosphere affects not only the climate but also plays role in the socio-economic growth of the region. Monitoring of the spatial and temporal variability of snow cover at high resolution is very much required as it provides valuable information for various weather and climate applications. In northern hemisphere snow covered area can reach above 40% of the Earth's land surface during the winter season [1]. Snow cover information can be used for various applications i.e. climate modelling, snow water equivalent estimation, snow melt run off prediction, avalanche forecast and energy balance modelling. Satellite remote sensing is a useful tool for snow studies as it can provide near real-time data to study [2].

In the present study satellite data from Advanced Wide Field Sensor (AWiFS) on-board Resourcesat-1 satellite and AWiFS-II sensor on-board Resourcesat-2 satellite have been used for snow cover mapping in Himalayan region. Due to the high radiometric resolutions this satellite data not only helped us in overcoming the saturation problem but also facilitate the effective monitoring of large snow covered areas frequently because of high temporal resolution and wide swath [3]. However, mountain shadow and confusing signature of snow and cloud in the visible and near-infrared region is a major difficulty in snow cover monitoring [4]. At present various methods exists for snow cover monitoring i.e. Normalized Difference Snow Index (NDSI), Snow Index 3(S3) etc. [5]. NDSI based methods can provide more reliable outputs as they can give the snow information from mountain shadow also. NDSI is successfully used by various researchers to differentiate snow and non snow regions by using the high and low reflectance of snow in the visible (green) and shortwave infrared (SWIR) regions respectively [6]. A threshold of 0.4 value of NDSI is reported for snow cover identification. The NDSI can be computed by equation 1.

$NDSI = (R_{Green} - R_{SWIR}) / (R_{Green} + R_{SWIR})$ (1)

Where R_{Green} is reflectance of green band (0.52-0.59 μm) and R_{SWIR} is reflectance of SWIR band (1.55-1.70 μm).

2. STUDY AREA

The study area lies in North-West Himalayas. Three basins i.e. Chenab, Jhelum and Kishanganga are taken into consideration. Chenab basin comprises of two sub basin Chandra and Bhaga. Jhelum basin comprises of five sub basins i.e. Gulmarg, Uri, Sind, Pahalgam and Banihal. The study area is extending from latitude 32° 00' 00" N to 35° 00' 00" N and longitude 74° 00' 00" E to 78° 00' 0" E. Mean elevation of the area lies between 1100 m and 6500 m. Maximum precipitation being experienced during November to February month and the temperatures during this period remains towards lower side.

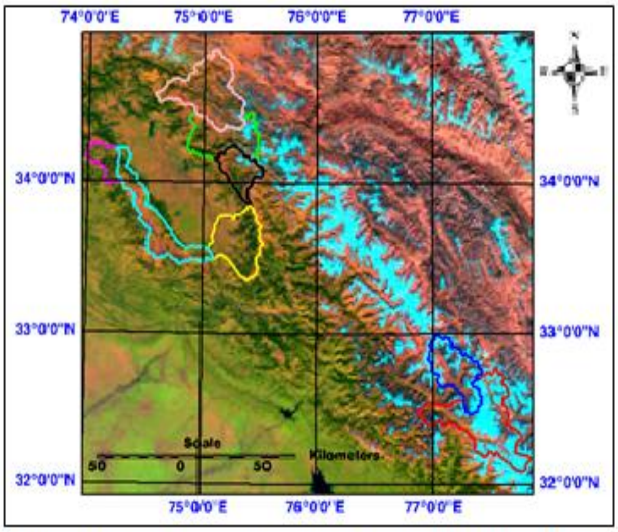

Figure1: Study area showing North-West Himalayas

Uri — Gulmarg — Pahalgam — Banihal
Sind — Kishanganga — Bhaga — Chandra

3. DATA USED

3.1Ground observatory data

Snow and Avalanche Study Establishment (SASE) has various snow-meteorological observatories in Himalayan region. In these observatories data of snowfall, standing snow, snow surface temperature, minimum temperature, maximum temperature etc is collected manually. These manually collected data's are used in the present study in the support of the satellite derived snow cover results.

3.2 Satellite data

In the present study the cloud free imageries of AWiFS and AWiFS-II from October 2004 to May 2013 are used. Survey of India (SOI) map sheets at 1:50,000 scales are used for the generation of Digital Elevation Model (DEM). Specifications of AWiFS [7] and AWiFS-II [8] sensors are given in the table 1 and table 2 respectively.

4. METHODOLOGY

4.1 Satellite data processing

The ERDAS Imagine 9.2 software is used for the pre-processing of satellite data. Scenes of AWiFS and AWIFS-II sensors are geocoded with respect to master scene of the study area. Due to inbuilt distortion in the image the data sensed by the sensors cannot be used as it is. The master image is generated from 1:50,000 topo-sheets. DEM generated from SOI map sheet is used to ortho-rectify the images. The detailed methodology is explained in the flow chart.

4.1.1 Conversion of DN (Digital No.) image to Radiance image

Satellite received DN images after geometric corrections are first converted in Radiance images by using equation (2). $L_\lambda = (DN\times(L_{max}-L_{min})) / DN_{max} + L_{min}$ (2)

Where L_λ= spectral radiance at the sensor's aperture, L_{min}= minimum value of radiance, L_{max}= Maximum value of radiance, DN_{max} = Maximum of DN values for a particular band, DN =Digital number of a pixel in a particular band.

4.1.2 Atmospheric correction and Reflectance image

The atmospheric corrected image is obtained by the applying Dark Object Subtraction Model (DOS Model). The reflectance is estimated using atmospheric corrected radiances, solar zenith angle, earth sun distance and exo-atmospheric spectral irradiance as given below in equation (3) [9].

$R_\lambda = \pi L_\lambda D^2 / (E_{Sun\,\lambda} \cos\theta_z)$ (3)

Here R_λ is the reflectance of a pixel in a particular band, L_λ is corrected spectral radiance (mW/cm^2/sr/µm), d is earth–sun distance in astronomical units (AU), E_{sun} is mean solar exoatmospheric spectral irradiance (mW/cm^2/µm) and z is the solar zenith angle calculated for each pixel of the study area.

The values of the mean solar exo-atmospheric spectral irradiance ($E_{sun\lambda}$) for AWiFS bands 2-5 are 185.111, 158.376, 110.251 and 24.042 mWcm^{-2} µm^{-1} respectively.

While processing the satellite data sometimes the output images are having maximum value of reflectance greater than 100 % and those images are further normalized by using normalized reflectance model.

4.1.3 Normalized Difference Snow Index (NDSI)

To estimate snow cover under the mountain shadow the reflectance based methods are not sufficient. In the present study NDSI is used to retrieve the snow cover information. NDSI can also used to discriminate between snow and cloud

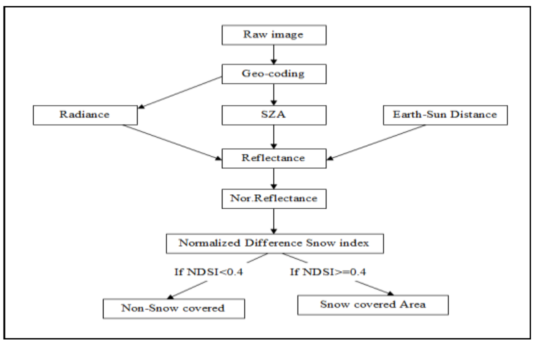

Figure 2: Flow chart of Methodology

To differentiate the snow and non-snow covered area in a pixel, a threshold of 0.4 is used in NDSI image.

NDSI images have been generated and further used to estimate percentage snow covered areas in the different basins.

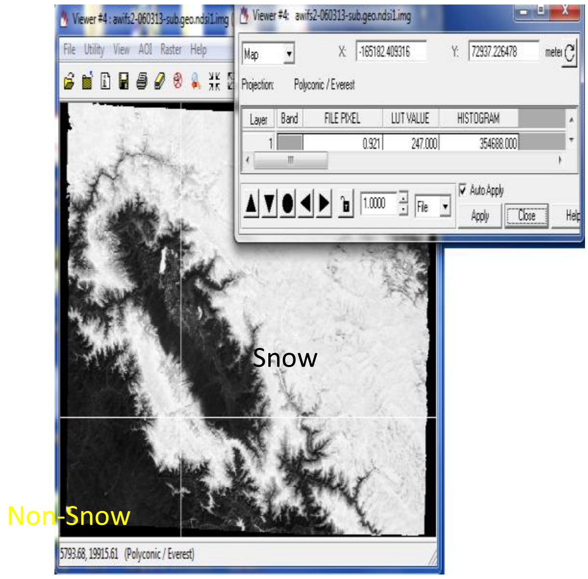

Figure 3: NDSI image of AWiFS-II sensor

4.1.4 Mann Kendall test

The Mann-Kendall test is a non-parametric test for recognising trends in time series data [10]. In this test, the percentage of snow cover area of each month is compared with remaining months of a year. The variance is calculated by using equation (4) as given below:

$$Z = \frac{S}{\sqrt{\frac{n(n-1)(2n+5)}{18}}} \qquad (4)$$

Where S= number of data points with positive values minus the number of cells with negative values

n=Total number of months in all years.

Z= variance.

In the present study Mann Kendall test is used to obtain trend of % SCA in different sub-basins of NW Himalaya.

Satellite	Sensor	Temporal resolution(days)	Radiometric resolution	Spatial resolution (m)	Swath (km)
Resourcesat-1	AWiFS	5	10 bit	56	740

Table 1. Specification of AWiFS sensor

Satellite	Sensor	Temporal resolution(days)	Radiometric resolution	Spatial resolution (m)	Swath (km)
Resourcesat-2	AWiFS-II	5	12 bit	56	740

Table 2. Specification of AWiFS-II sensor

Results and Discussion The trend of seasonal snow cover variation in Gulmarg sub-basin for 9 years (2004-2013) is shown in figure 4.

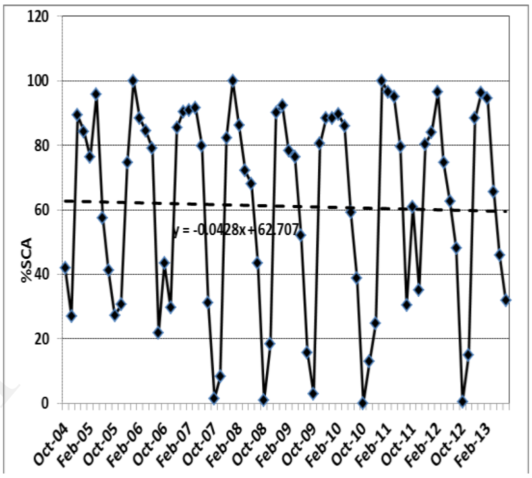

Figure 4: Variation of % SCA in Gulmarg Sub-basin (2004-2013)

From above figure a slightly negative trend has been observed in the % seasonal snow cover area. Although this negative trend is statistically non-significant.

Further we analysed % SCA trend in Gulmarg sub-basin for different months also. Figure 5(a)-(h) shows the variation of % SCA in different months. After analysing these graphs the rate of change of % SCA in different months for last nine years (2004-13) is summarized in table 3.

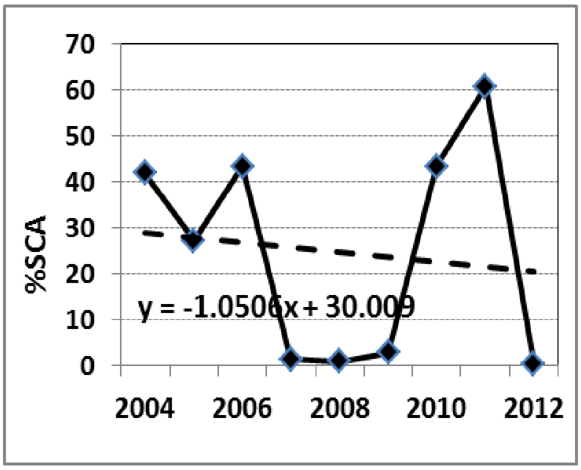

Figure 5(a): Variation of SCA (Oct.)

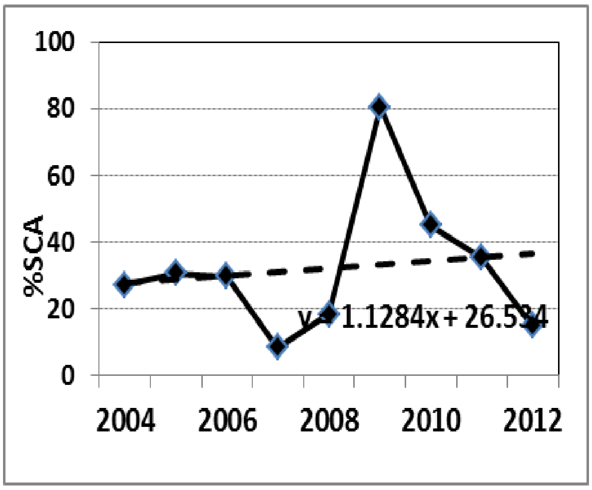

Figure 5(b): Variation of SCA (Nov.)

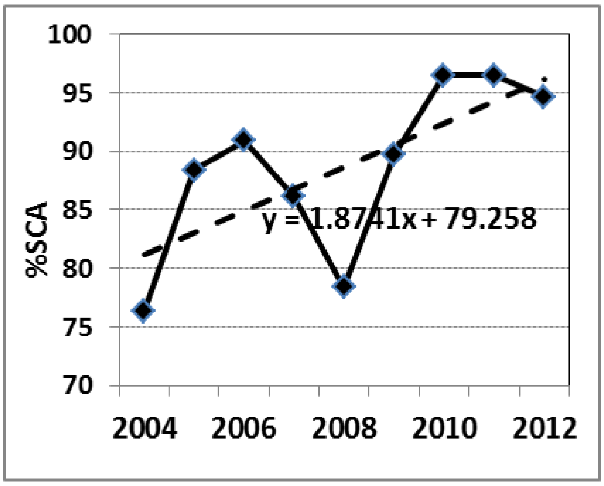

Figure 5(e): Variation of SCA (Feb)

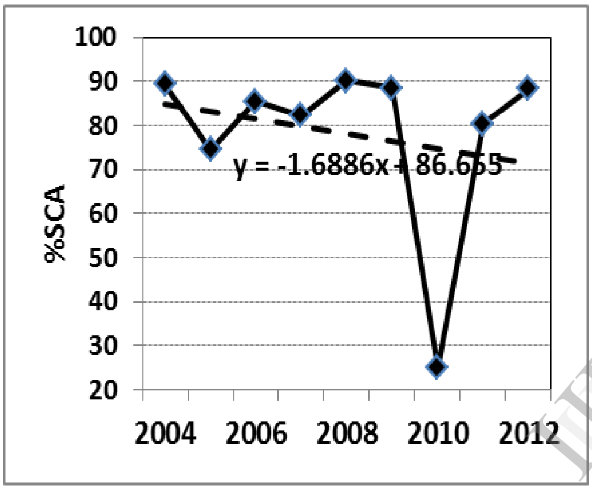

Figure5(c): Variation of SCA (Dec.)

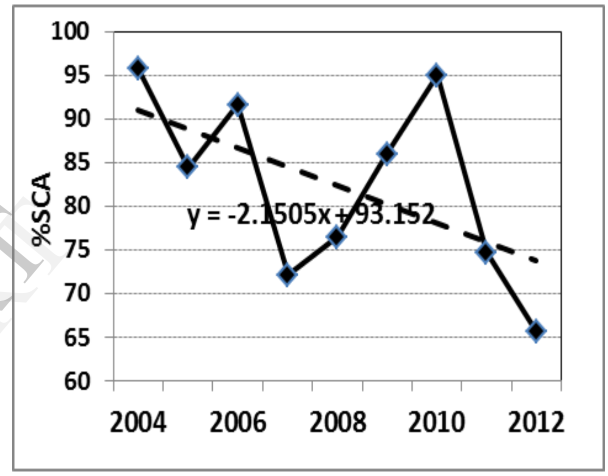

Figure 5(f): Variation of SCA (Mar.)

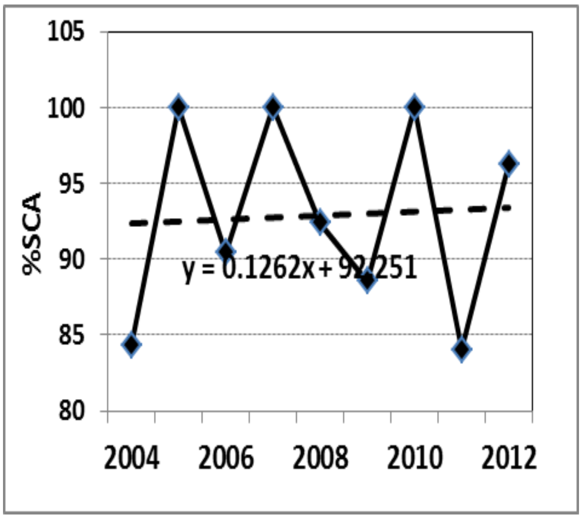

Figure 5(d): Variation of SCA (Jan.)

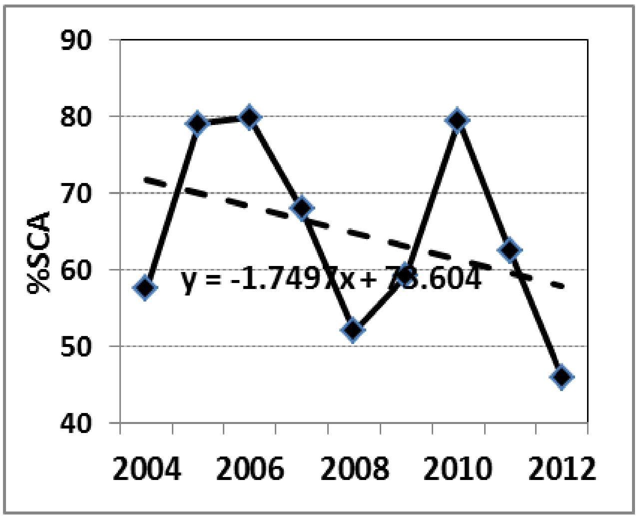

Figure5 (g): Variation of SCA (Apr.)

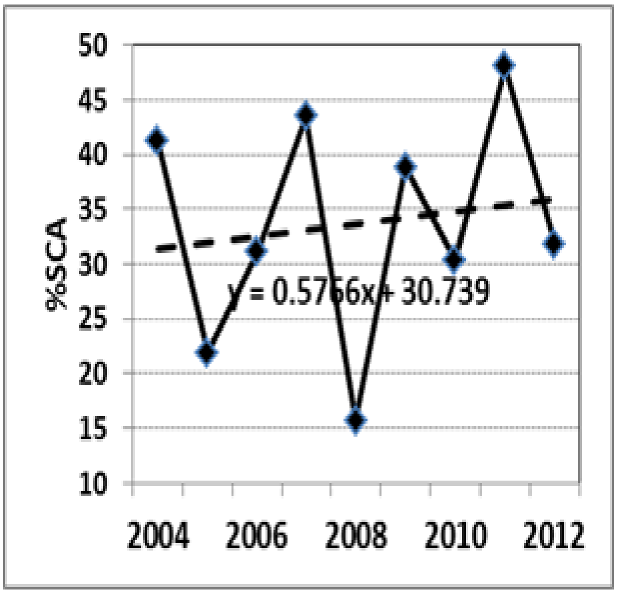

Figure 5(h): Variation of SCA (May.)

After analysing Figure 5(a)-(h) an increasing trend in SCA has been observed for Nov., Jan., Feb. and May months. However decreasing trend has been observed for Oct., Dec., Mar. and April months. During peak winter month i.e. Jan. the rate of change in SCA is very less comparison to other analysed months. Rate of change in SCA is observed highly decreasing in March and April month as given in table 3 and the same is mostly contributing in the seasonal trend of SCA also.

Month	Rate of change (%SCA)
Oct	-1.05%
Nov	1.13%
Dec	-1.69%
Jan	0.13%
Feb	1.87%
Mar	-2.15%
April	-1.75%
May	0.58%

Table 3: Rate of change of % SCA

In order to observe the average values of SCA in different months, we have taken the average of last 9 years and the variation of the average SCA is shown in Figure.6. From the graph it can be inferred that in Gulmarg sub-basin snow cover starts building up from Oct. month onward. The maximum SCA reaches in Jan. and after that it starts decreasing. From Figure. 6 and table 4 it has been observed that in Gulmarg sub-basin snow persists for longer duration as SCA around 33% has been observed even in May month.

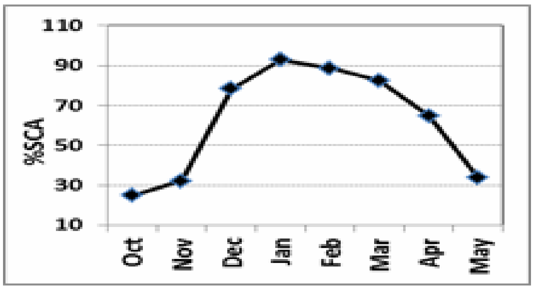

Figure 6: Variation of average SCA in different months

Month	Avg. (% SCA)
Oct	24.76
Nov	32.18
Dec	78.21
Jan	92.88
Feb	88.63
Mar	82.40
April	64.86
May	33.62

Table 4: Average SCA in different months (Gulmarg sub-basin)

Figure 7, shows the monthly variation of SCA for period 2004-13.

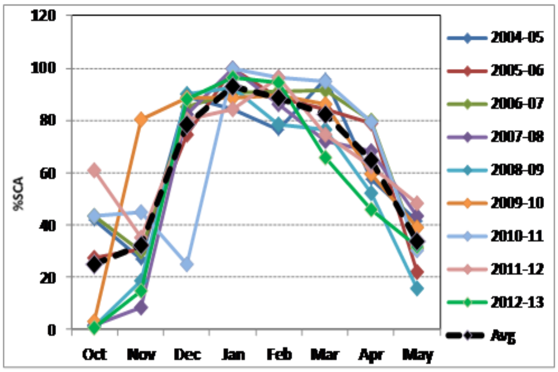

Figure 7: Temporal Variation of SCA in Gulmarg Sub-basin

From the figure it is observed that the pattern of snow cover build up and depletion is remained almost similar in last 9 years. Further we have also analyzed the yearly average SCA in last 9 years. The result of this is presented in Figure. (8). from the figure lesser SCA has been observed in year 2007, 2008 and 2012. Overall a decreasing trend has been observed in yearly average SCA values.

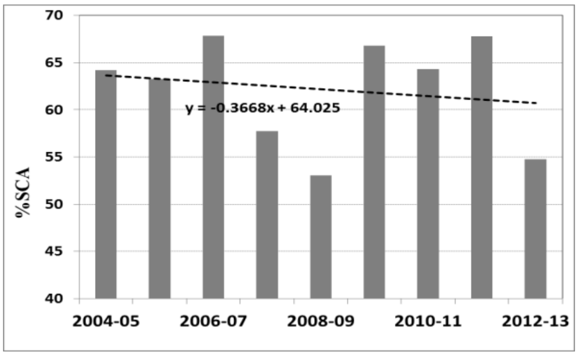

Figure 8: Temporal Variation of yearly average SCA values

The areal extent of snow in a region depends mainly on its metrological and terrain parameters. Figure 9 shows the variation of average ambient temperatures for Gulmarg sub-basin for the period 2004-13.

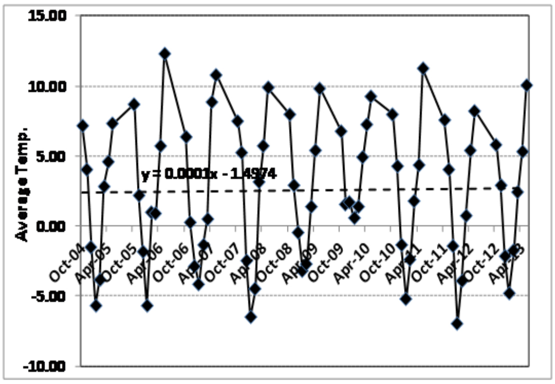

Figure 9: Temporal variation of monthly averaged ambient temperature

From Figure.(9) a statistically non-significant increasing trend has been observed in average ambient temp. of Gulmarg sub-basin. This increasing trend in average ambient temp. can be correlated with the decreasing trend in the SCA as
presented in Figure 4 .

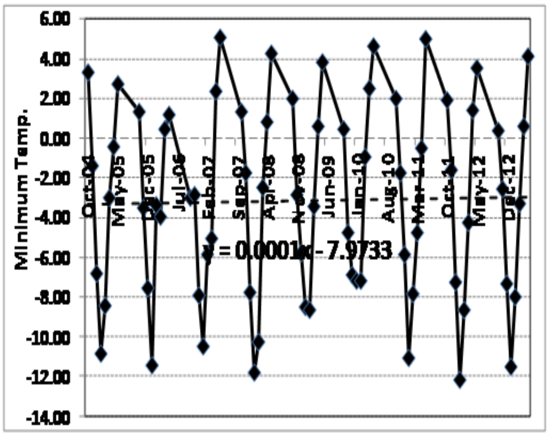

Figure 10: Temporal variation of monthly averaged minimum temperature

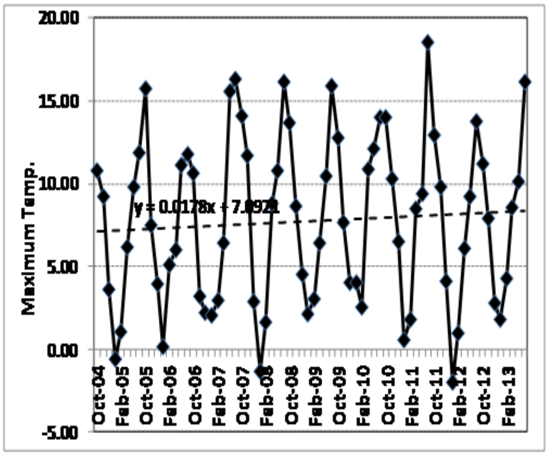

Figure 11: Temporal variation of monthly averaged maximum temperature

Figure 10 and 11 shows the variation of monthly averaged minimum and maximum temperature for Gulmarg sub-basin. From the graphs it is observed that the minimum and maximum both have increasing trend. However the rate of this increase is significant for maximum in comparison to the minimum. Thus the decreasing trend of SCA in Gulmarg sub-basin can be correlated with the significant increase of maximum temp for the same period.

Sub-basins	Rate of Change (%SCA)
Banihal	-0.82%
Gulmarg	-0.37%
Pahalgam	0.39%
Kishanganga	-0.92%
Uri	-1.19%
Sind	-0.65%
Bhaga	-0.28%
Chandra	0.14%

Table 5: Rate of change in % SCA on yearly basis for different sub-basins

% SCA for different sub-basins has been estimated on monthly basis and further from this data the yearly average values of % SCA were calculated. The rate of change in % SCA on yearly basis for different sub-basins is given in table 5. From the data negative trend in % SCA is observed for most of the sub-basins

CONCLUSION

In the present study variation in the snow cover has been monitored for different sub-basins of northwest Himalaya. Most of the areas in northwest Himalaya have shown decreasing trend of snow cover. Detailed results of Gulmarg sub-basin have shown that the temperature of the region is one of the important factors responsible for the decreasing trend of SCA in this sub-basin. Although maximum and minimum temperature both have shown increasing trend but the rate of increase of maximum temperature which is responsible for melting/depletion of snow cover is comparatively very high than the rate of increase of minimum temperature. The average values of SCA in different months is one of the important information and will be helpful for tourism industry as Gulmarg sub-basin is an important tourist attraction area for snow sports. Also the inferences drawn from the study can be one of the important input for snow melt run off study of Jhelum river.

REFERENCES

[1] Robinson D.A. and Kukla G. Maximum surface albedo of seasonally snow covered lands in the northern Hemisphere; J. Climate and Applied Meteorology 1985, 24,402–411.

[2] Konig M., Winther J .G. and Isaksson E. Measuring glacier properties from satellite; Rev. Geophys. 2001, 391–27.

[3] Kulkarni A.V., Singh S. K., Mathur P. and Mishra V. D. Algorithm to monitor snow cover using AWiFS data of RESOURCESAT-1 for the Himalayan region; Int. J. Remote Sensing 2006,27(12) ,2449-2457.

[4] Dozier J. Spectral signatures of snow in visible and near-IR wavelengths; Proceedings of the 3rd International Colloquium on Spectral Signatures of Objects in Remote Sensing, Les Arcs, France, 1985, December, 16–20,ESA-SP-247.

[5] Devesh Khosla, J.K. Sharma, V.D. Mishra, Snow cover monitoring using different algorithm on AWiFS sensor Data, International Journal of Advanced Engineering Sciences and Technologies, , 2011, Vol No. 7, Issue No. 1, 042-047.

[6] Kulkarni A. V., Srinivasulu J., Manjul S. S. and Mathur P. Field based spectral reflectance to develop NDSI method for the snow cover; J. Indian Soc. Remote Sens. 2002b, 30(1&2), 73–80.

[7] S. Subramaniam, A.V. Suresh Babu, E .Sivasankar, V. Venkateshwar Rao and G. Behera , Snow Cover Estimation from Resourcesat-1 AWiFS-Image Processing with an Automated Approach, International Journal of Image Processing (IJIP), 2011, Vol(5), Issue(3), 298-320.

[8] Priyanka Handa, V. D. Mishra and J.K Sharma, New algorithm for automated snow cover monitoring and understanding impact of topographic influence on sub-pixel analysis using AWiFS-II on Himalaya, International Journal of Engineering Research and Technology, July 2012, Vol. 1, Issue 5.

[9] Dozier J. F., Snow reflectance from Landsat-4 Thematic mapper. IEEE Transactions on geosciences and remote Sensing, 1984, 22(3), 323–328.

[10] Hirsch, R.M., Slack, J.R. and Smith, R.A. Techniques for trend assessment for monthly water quality data, Water Resources Research, 1982, 18,107–121.