ESTIMATION OF SNOW GRAIN SIZE AND TEMPERATURE USING HYPERSPECTRAL AND MULTISPECTRAL DATA

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ABSTRACT

Snow undergoes constant change becomes essential matter in earth's climate and hydrological system. In India snow covered areas found in rugged/ mountainous region in the Himalayas. For such a terrain satellite data provide timely and efficient information. A study was undertaken to integrate estimation of physical parameters of snow based on ground truth data collection and satellite data. The SOI toposheet at 1:50000 scale was used. DEM was generated using ASTER data to for elevation and slope. For physical parameter estimation, multispectral and hyperspectral satellite data were digitally processed using ERDAS Imagine, ArcGIS and ENVI software. Landsat-8 data of October 2016 were used for generating Land use/Land cover map and surface temperature map. Also, Hyperion data of January 2016 were used for snow grain size studies. Out of 220 bands, selected bands only used for processing. Preprocessing involves removal of bad bands, bad column and removing the influence of the atmosphere. FLAASH atmospheric correction model is applied on Hyperion data to retrieve surface reflectance in ENVI 5.1 software. Snow grain size has been estimated using spectral angle mapper (SAM) and grain index (GI) method. Spectral reflectance for different grain size was collected in field, using optical spectroradiometer and compared with satellite derived spectra during February 2017. Snow has high reflectance in visible and low in SWIR. Comparing results of SAM and GI it is revealed that GI shows higher percentage of fine grained snow than SAM and this could be attributed to cloud covered areas getting misclassified in SAM. The results obtained by the GI classification method appear to be more factual, as snowfall being more during the month of January. Thus, it is concluded that by integrating field based observations and image processing methods applied on satellite data provide more accurate estimation for snow studies.

1. INTRODUCTION

The analysis of snow properties plays a key role in hydrological and climate model especially due to snowmelt runoff in mountainous region. In context Indian Himalayan understanding physical properties of snow is very important due to the fact that they are perennial source of water, hydropower generation and have a say in regional climatology. However, mapping of snow and its physical parameters is very difficult using field instruments due to rough terrain, harsh weather conditions and only point observations provided. The remote sensing has emerged as an alternative technique for snow studies to overcome these difficulties. Satellite remote sensing is one of the important and proven tools for the mapping and monitoring of vast, rugged and remote snow covered areas. Landsat data have been used to determine snow grain size (Bourdelles et.al. 1993, Nolin et.al. 2000, Konig et. al. 2001, Li et. al.2001, Painter et. al. 2003, Koren et. al. 2009 and Zege et. al. 2013). The spectral properties of snow in the optical region have been studied by many authors (Bohren and Barkstrom 1974) and Hyperion region (Pearlman et.al. 2003, Dozier et.al. 2004, Negi et.al. 2010, and Singh et.al. 2012). Properties of snow and ice like albedo, snow grain size, and snow surface temperature, snow density etc. are important input parameters for various modelling surface runoff and energy balance models.. Further creating a data base of such processes from field input and up scaling them on satellite data helped in better understanding of snow formation. In the present study use of multispectral and hyperspectral remotely sensed data namely LANDSAT -8 and Hyperion were compared for snow bound areas. The multispectral sensors usually have between 3 and 10 different band measurements in each pixel of an image covering relatively broad wavelength regions. On the other hand hyperspectral sensors collect image data simultaneously in hundreds of narrow (10-20 nm) adjacent spectral bands using spectrometer. These measurements make it possible to derive a continuous spectrum for each image cell. The hyperspectral remote sensing has an added advantage of providing point observations, thus providing minute information on the snow properties. Hyperion is a sun-synchronous (polar) orbit sensor at an altitude of 705 km having push-broom scanner with a high spectral resolution with 242 contiguous, narrow bandwidth bands was used for the study. The Spatial resolution is 30 m (ground sample) with a swath width of 7.7 km and covers an area of 7.7x100 square km per image with high radiometric accuracy.After adjustments for sensor, atmospheric, and terrain effects are applied, these image spectra can be compared with field or laboratory reflectance spectra in order to recognize and map snow. The convergence of two distinct technologies, spectroscopy and the remote imaging of Earth surfaces are used for snow studies. Spectroradiometer was used to for measuring light reflected from snow bound areas in the field. The overall shape of a spectral curve and the position and strength of absorption bands can be used to identify and discriminate different properties of snow and other surrounding materials. The spectral measurements are compared with standard reference material with known spectral reflectance. The study involves characterization of physical and optical properties of different forms of snow and how they are formed, using ground truth data collection and remote sensing techniques. Focus of the study is on snow grain size, land surface temperature, density and wetness of volume of snow. For this purpose field and satellite based data were processed to retrieve the required physical parameters. Image processing involved retrieval of snow grain size using supervised classification and corroborate with field data.

2. STUDY AREA

The study area is highly dissected mountain ranges separated with deep gorges and valleys of Kullu district of Himachal Pradesh state located in northern India. It is also characterized with diverse climate that varies from semi tropical in lower hills to semi arctic in cold deserts areas of Spiti and Kinnaur. The area of interest includes a stretch from Dhundi (latitude 32˚21'22"N, longitude 77˚07'42"E) to Solang (latitude 32˚19'27" N, longitude 77˚09'27"E). Dhundi and Solang are situated in Beas basin in the Pir Panjal mountainous regions (Figure1). Dhundi is 9 km from Solang situated at an elevation of 3080 m is the last village in the Solang valley where Beas river meets its first tributary coming from Beas kund. Solang is 14 km northwest from the famous town Manali in Kullu district at an elevation of 2560 m. The main course of river Beas flowing from north to south in a zigzag manner is a perennial river fed by snow melt water and rainfall. The hill sides are much exposed as it is surrounded by few trees but forest covers almost all the higher slopes. The rocks found in the study area are comprised of the Precambrian crystalline schists and gneiss of the Jutogh and the Chail formations. Both these formations represent low to high grade metamorphic rocks such as mica chlorite schist, phyllites, and schistose quartzites. Due to snowfall occurring during December and January at elevation above 2500 meters area is cut off from the lower region. Temperatures fluctuate from minimum -15°C and 0° in January to maximums up to 30°C in June.

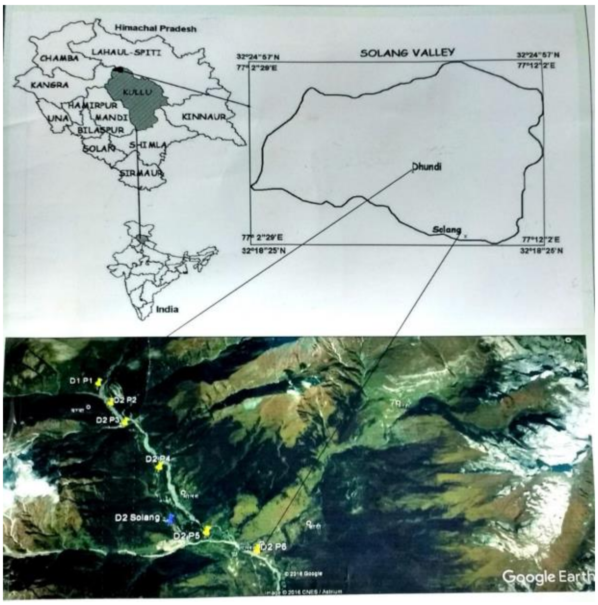


Figure 1 Location of the study area

3. DATA AND METHODS

3.1 Data

The data pertaining to physical properties of snow such as grain size, density, temperature, etc were collected during field visit from Dhundi to Solang in the month of February, 2017 (Figure 2) using field and laboratory based techniques. A portable snow fork instrument was used for measuring wetness and density, snow crystal card was used for estimating snow grain size (Figure 3) and dial stem thermometer was used to measure the snow surface temperature. The study area lies in the SOI toposheet number 143X3 of scale 1:50000. ASTER GDEM V2 (Advanced Spaceborne Thermal Emission and Reflection Radiometer, Global Digital Elevation Model) with 30-meter postings and 1x1 degree tiles was used for generating DEM.

Figure 2 Fresh snow observed at Dhundi site on 12th February 2017

Figure 3 Snow fork and Snow crystal card

The Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) data of Landsat 8 of October 2016 were used to generate land use/land cover map by visual interpretation using ERDAS. The radiometrically corrected Hyperion image of L1R over Dhundi-Solang region was acquired (Table 1). The dimensions of the acquired dataset are 256 (ground samples of 30m width) x 3129 (lines) x 242 (bands). The acquired data fall in the wavelength range from 355.589 nm to 2577.070 nm at approximately 10 nm sampling interval.

Table 1 Details of Hyperion data

Data Attribute	Attribute value	Data Attribute	Attribute value
Entity ID	EO1147037201602311OPD	Scene Start Time	03:39:45
Acquisition Date	2016-01-23	Scene Stop Time	03:44:22
NW corner	33.339385,77.343791	Target Path	147
NE Corner	33.325725,77.421360	Target Row	37
SW Corner	31.398888,76.821581	Sun Azimuth	129.840761
SE Corner	31.385339, 76.897615	Sun Elevation	19.228868
Cloud cover	10% to 19%	Product creation time	2016-01-25
Acquisition Date	2016-01-23	Look Angle	5.3781
Receiving station	AK3	Satellite Inclination	97.98

The satellite data of Landsat 8, ASTER GDEM and Hyperion of study area were downloaded from Earth explorer website earthexplorer.usgs.gov. The ArcGIS 10.2, ERDAS IMAGINE 2014 and ENVI 5.1 software were used for analysis and image processing.

3.2 Methods

Snow fork is designed to operate in extreme conditions, ranging from rainy weather to as low as 40^{o} C below zero. The sensor is a steel fork used as a microwave resonator. Snow Fork measures the electrical parameters: resonant frequency, attenuation and 3-dB bandwidth. The measuring results are used to calculate accurately the complex dielectric constant of snow. Further, the liquid water content and density of snow are calculated using semi-empirical equations. Snow crystal card having 1mm, 2mm and 3mm grids are laser etched for precision when estimating snow grain sizes. Snow sample is collected from the top layer and gently spread over the plastic card such that the snow is retained on the card and examined the snow with a hand lens. The toposheet was georeferenced in ArcGIS 10.2 and World Geodetic System (WGS 1984) 43N Zone was selected for Indian coordinates to get the shapefile of the study area. A number of satellite data sets have been used to achieve the various objectives. Land use / land cover pattern of any terrain is reflection of the complex physical processes acting upon the surface of the earth. The supervised classification was used for preparing LU/LC map. A subset of the image was processed in ERDAS by using open signature editor to add training samples of each class using the AOI tool and the image was classified using maximum likelihood method. Land surface temperature (LST) was calculated using brightness temperature of thermal bands of TIRS sensor and Land surface emissivity (LSE) from optical bands of OLI sensor of Landsat 8 data (Chen et.al. 2014) as per equation 1. Thermal bands wavelengths (band 10 and band 11) were used for calculating LST in ArcGIS. TIRS band data converted to TOA spectral radiance using the radiance rescaling factors provided in metadata file to calculate TOA spectral radiance. This value was used in calculating brightness temperature in turn arriving at LST. The LST is defined by:

$$\text{LST} = BT / (1 + w * BT/P * \ln(e)) \quad (1)$$

Where BT = at satellite temperature, w = wavelength of emitted radiance (11.5µm), p = $h*cs*(1.438*10-2m\ K)$, h = Planck's constant (6.626 * 10-34 Js), s = Boltzmann constant (1.38 * 10-23 J/K), c = velocity of light (2.998 * 108 m/s), p = 14380, e =land surface emissivity (.004 Pv + 0.986), Pv is proportion of vegetation $(NDVI-NDVImin / NDVImax-NDVImin)^2$.

The Hyperion sensor has two spectrometers operating over different spectral ranges- Visible and near Infrared region (VNIR) i.e. 0.4 to 1µm having 70 bands and Shortwave Infrared region (SWIR) i.e. 0.9 to 2.5µm having 172 bands. Preprocessing involves huge volume of spectral data necessitates removal of sensor error during data acquisition, band selection as well as to remove band column and negative pixels values and reduce the computational complexity. The pre-processing in this study involved - bad band removal i.e. removing the bands with no information, along track destriping, Atmospheric corrections to convert the radiance to reflectance using FLAASH and Geometric correction.

For grain size retrieval supervised classification spectral angle mapper (SAM) method was used and for snow grain size mapping Grain Index (GI) method was used. The SAM algorithm determines the spectral similarity between the two spectra (i.e. the pixel spectra to known/reference spectra) by calculating the angle between two vectors representing these spectra. To evaluate the selected methodology and classification results, the selection of endmembers based on “Spectral Hourglass” processing scheme involved following steps- Minimum Noise Fraction transform (MNF), Pixel Purity Index (PPI) and n-Dimensional (n-D) visualization approach was adopted. The algorithm determines the similarity between two spectra by calculating the spectral angle between them, treating them as vectors in n-D space, where n is the number of bands.
The snow grain size map was prepared using the grain index method proposed by Negi et al. (2010) and used by Negi et al. (2013) based on the field-collected Hyperspectral reflectance data. Hyperion band number 24 (589.62nm wavelength) and band number 90 (1043.59 nm wavelength) is used to calculate grain index. Snow grain size map were generated using the threshold values 0.0-0.17, 0.17-0.26 and 0.26-0.37 for the fine, medium and coarse grain size respectively.

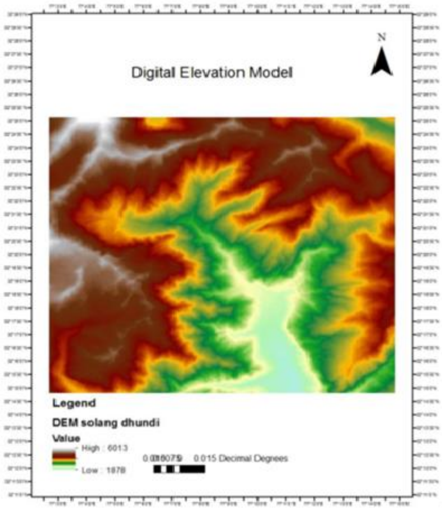
4 RESULTS AND DISCUSSION

The hand held GPS of GARMIN was used for precise location of sample collection of snow. The results of pPhysical properties of snow like grain size, density, temperature and wetness etc. were measured (Table-2).

Table 2 Physical parameters of snow measured in the month of Feb 2017 from Dhundi to Solang

Point	**Lat (N)**	**Lon (E)**	**Elevation (m)**	**Accuracy**	**Density (g/cc)**	**Grain Size (mm)**	**Wet of volume**	**Temp**	**Time**
D1 P1	32° 21' 19"	77° 07' 35"	2890.32	7.2	0.1982	0.6-0.7	7.048	- 2°C	11:30 AM
D2P1	32° 21' 58"	77° 07' 51.1"	2774	6.1	0.3125	1	4.675	-2°C	12:57 PM
D2 P2	32° 20' 55.1"	77° 07' 53.4"	2777.3	9.3	0.1517	1-1.5	6.224	- 3°C	1:32 PM
D2 P3	32° 20' 32.2"	77° 08' 13"	2727	8	0.1439	0.1	0.540	- 6°C	2:00 PM
D2 P4	32° 19' 44.8"	77° 08' 55.3"	2570	6.1	0.2376	1.5-2	5.402	- 3°C	2:30 PM
D2	32° 18' 53.1"	77° 09' 12.3"	2502.5	6.9	0.2922	2	4.630	-3.5°C	3:12 PM
D2 P5	32° 18' 43"	77° 09' 47.4"	2398.3	6.4	0.2177	2-2.5	5.577	- 3°C	4:13 PM
D2 P6	32° 18' 26.5"	77° 10' 34.9"	2251	6.4	0.2820	2	5.792	- 3°C	4:30 PM

From the DEM it is observed that study area got an elevation from 1878 m to 6013 m above mean sea level, which indicated the rugged mountains and steep terrain with river Beas flowing from north to south in the central part of the map (Figure 4). The slope map was derived from DEM having classified into five classes (Figure 5). Both the results reaffirm that terrain is highly rugged with steep slopes.



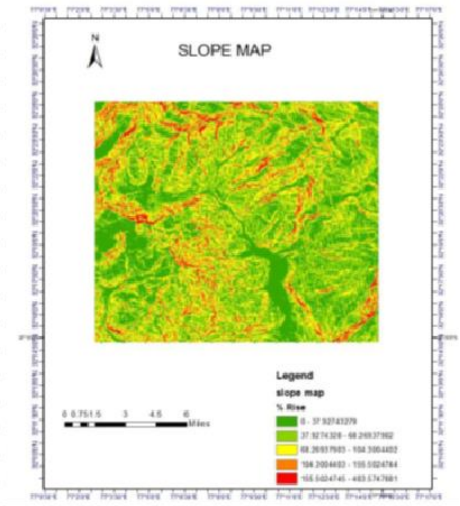


Figure 4 DEM of the Dhundi-Solang, Figure 5 Slope map Dhundi-Solang

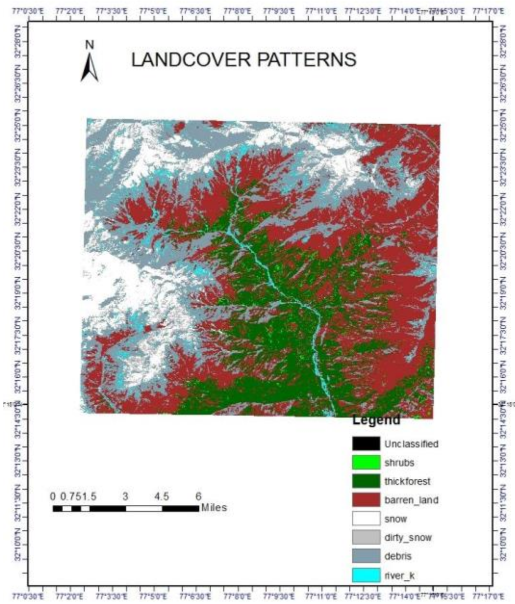


Figure 6 Landcover pattern map prepared from Landsat 8 October 2016

Physical description of earth surface of the study area was put into different classes of the LU /LC derived from Landsat 8 data. Because of low resolution of satellite image some of the classes get intermixed. The land cover pattern of the study area broadly categorized into seven classes i.e. snow, dirty snow, debris, river, barren land, shrubs and the forest cover (Figure 6). It is evident that all along the river thick forest and shrubs occupy land, whereas higher reaches are occupied with fresh snow and slopes are occupied by debris.

4.1 Retrieval of snow surface temperature and grain size

4.1.1 Land surface temperature

Land surface temperature (LST) was calculated using brightness temperature of thermal bands of TIRS sensor and Land surface emissivity (LSE) from optical bands of OLI sensor of Landsat 8 data. Thermal bands (band 10 and band 11) are used for brightness temperature calculations and NDVI is used for the calculation of land surface emissivity. It is clear from the resultant map that snow bound areas depicting green color in the image corresponds to cold region extending up to minus 12º C (Figure 7). Similarly warm regions are shown in white color extending up to 29º C. Thus, TIRS of Landsat 8 was useful in directly mapping surface temperature of the snow bound inaccessible areas.

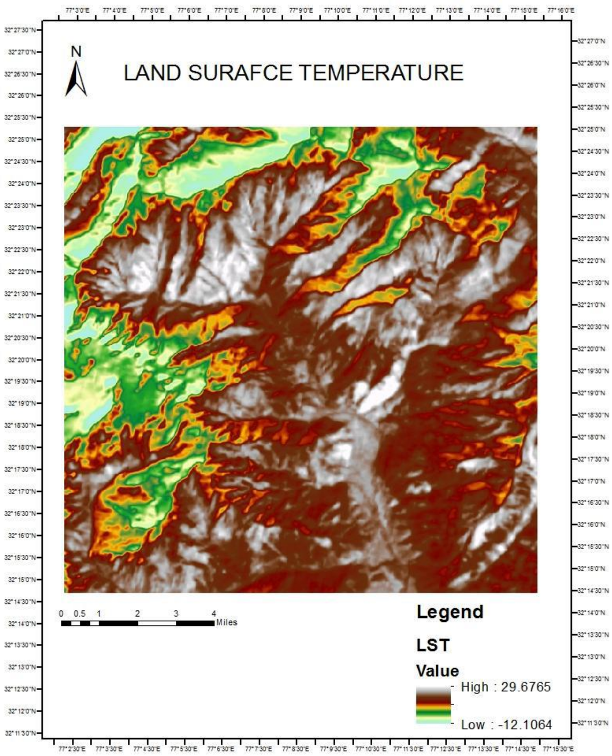


Figure 7 Land surface temperatures map

4.1.2 Spectral Angle Mapper (SAM) Classification

A qualitative analysis was done for the snow grain size classification using SAM shows the spatial distribution of

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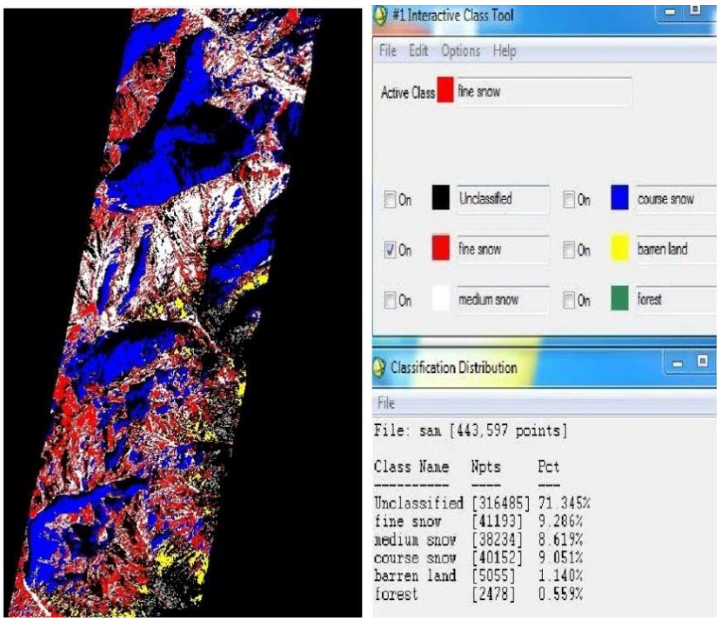

Figure 8 Classification of snow grain size using Spectral Angle Mapper (SAM)

different types of grain sizes of snow at a continuous scale (Figure 8). Three types of snow mainly fine, medium and coarse have been deciphered at the time of the scene and amounting to of 27% of total area. In addition to scene being devoid of data, the shadow portions got misclassified with unclassified category amounting to 71%. Further, scene being of January other features barren land and forest categories 1.140% and 0.559% respectively were demarcated. Thus SAM classification is very useful technique for snow grain size in inaccessible terrain.

4.1.3 Snow grain size mapping using Grain Index (GI) method

Normalized snow differential index (NSDI) was calculated and a mask is generated to take the values of NDSI above 0.4. NDSI mask was applied on atmospherically corrected Hyperion scene and snow grain size mapping was then done using Grain index method (Table 3). Based on the threshold values given by (Negi et al 2013) grain size map was prepared. It is observed that fine fraction of the snow grain size is well corroborated with GI method and could be due to the fact that fresh snow will be more present in the month of January (Figure 9). From the study it is clear that for grain size SAM classification present the true ground condition of the snow whereas GI is found to be more reliable for snow grain mapping.

Table 3 Showing threshold values, grain size and area in percentage

Sr. No.	Threshold values	Grain size	Percentage area
1	0-0.17	Fine grain (<0.5mm)	17.03 %
2	0.17-0.26	Medium grain (0.5-1.0 mm)	4.529 %
3	0.26-0.37	Coarse grain (1-2mm)	1.873 %
		Unclassified	76.575 %

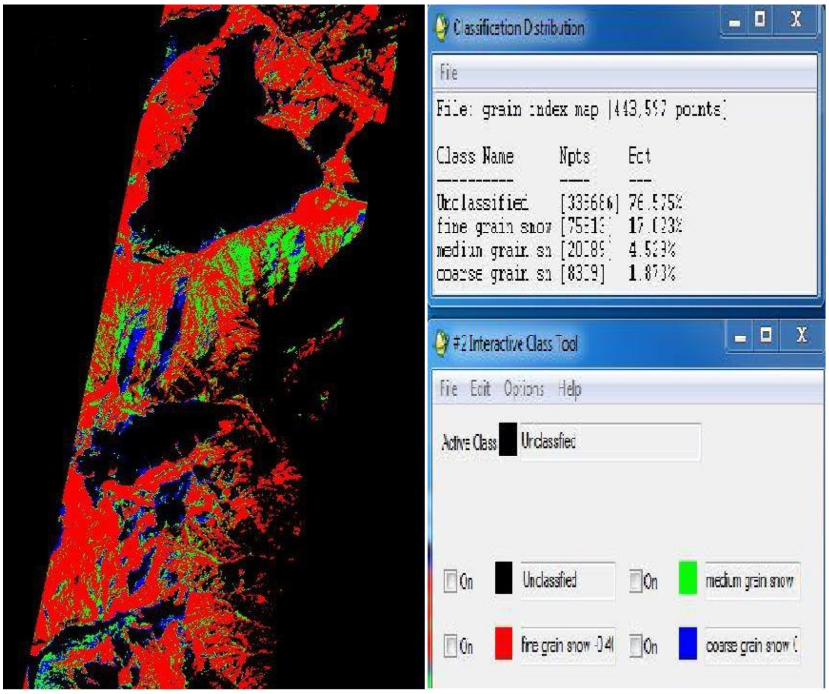

Figure 9 Spatial distribution of snow grain size using GI method in the study area

5 CONCLUSIONS

The study demonstrates potential of LANSAT 8 and ASTER DEM for bringing out of physical properties and accurate assessment of high and low features respectively of snow bound areas of inaccessible mountainous terrain. It is found that supervised classification produced better results in comparison to original image to extract landuse / landcover features present. Further, in the mountains terrain of snow bound areas it was possible to measure directly land surface temperature using TIR sensor of Landsat 8. DEM and slope map helped in delineating slopping pattern and drainage in the area. The SAM classification technique applied on to Hyperion data has shown encouraging results in measuring snow grain size quantitatively and further helped in deciphering classification of snow i.e. fine, medium and coarse amounting to 27% of total area. The GI classification technique applied on to Hyperion data quantitatively demarcated fine category of snow on the higher side appears to be more factual as the digital data was of the highest snow fall season i.e. January. The study reveals potential use of Hyperion data for the quantitative estimation of snow grain size and Landsat 8 could be used for directly measuring temrature. It is concluded that hyperspectral remote sensing technique has direct advantage over conventional methods in snow bound mountainous areas, as it provides contiguous spectral information over large spectral band with narrow band width.

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REFERENCES

Bohren, C.F. and Barkstrom, B.R., 1974. Theory of the optical properties of snow. Journal of Geophysical Research, 79(30), pp.4527-4535.

Bourdelles, B. and Fily, M., 1993. Snow grain-size determination from Landsat imagery over Terre Adelie, Antarctica. Annals of Glaciology, 17(1), pp.86-92.

Chen Du, Huazhong Ren, Qiming Qin, Jinjie Meng, Jing Li, 2014., Split-window algorithm for estimating land surface temperature from Landsat 8 TIRS data. IEEE, 978-1-4799-5775-0/14, pp.3578-3581.

Dozier, J. and Painter, T.H., 2004. Multispectral and hyperspectral remote sensing of alpine snow properties. Annu. Rev. Earth Planet. Sci., 32, pp.465-494.

König, M., Winther, J.G. and Isaksson, E., 2001. Measuring snow and glacier ice properties from satellite. Reviews of Geophysics, 39(1), pp.1-27.

Koren, H., 2009. Snow grain size from satellite images. Norsk Regnesentral, Note number SAMBA/31/09.

Li, W., Stamnes, K., Chen, B. and Xiong, X., 2001. Snow grain size retrieved from near-infrared radiances at multiple wavelengths. Geophysical Research Letters, 28(9), pp.1699-1702.

Negi, H.S., Jassar, H.S., Saravana, G., Thakur, N.K., Snehmani and Ganju, A., 2013. Snow-cover characteristics using Hyperion data for the Himalayan region. International journal of remote sensing, 34(6), pp.2140-2161.

Negi, H.S., Singh, S.K., Kulkarni, A.V. and Semwal, B.S., 2010. Field-based spectral reflectance measurements of seasonal snow cover in the Indian Himalaya. International Journal of Remote Sensing, 31(9), pp.2393-2417.

Nolin, A.W. and Dozier, J., 2000. A hyperspectral method for remotely sensing the grain size of snow. Remote sensing of Environment, vol. 74(2), pp.207-216.

Painter, T.H., Dozier, J., Roberts, D.A., Davis, R.E. and Green, R.O., 2003. Retrieval of subpixel snow-covered area and grain size from imaging spectrometer data. Remote Sensing of Environment, 85(1), pp.64-77.

Pearlman, J.S, Barry, P.S., Segal, C.C, Shepanski, J.,Beiso, D. and Carman, S.L., 2003. Hyperion, a space-based imaging spectrometer. IEEE Transactions on Geoscience and Remote Sensing, 41(6),pp.1160-1173.

Singh, M., Mishra, V.D., Jyoti, D.S.and Negi, A. (2012). Estimation of snow physical parameters using EO-1 Hyperion. IOSR Journal of Applied Physics, 1(6), pp.8-13.

Zege, E., Katsev, I., Malinka, A., Prikhach, A. and Polonsky, I., 2008. New algorithm to retrieve the effective snow grain size and pollution amount from satellite data. Annals of Glaciology, 49(1), pp.139-144.