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Discrimination of Seasonal Snow Cover in Astore Basin, Western Himalaya using Fuzzy Membership Function of Object-Based Classification

Suhaib Bin Farhan[1,2,*], Maham Kainat[1], Atif Shahzad[1], Adnan Aziz[1], Syed Jamil Hasan Kazmi[1], Saima Shaikh[1], Yinsheng Zhang[2], Haifeng Gao[2], Muhammad Naveed Javed[3], Umair Bin Zamir[1]

[1]Department of Geography, University of Karachi, University Road, Karachi, Pakistan
[2]Institute of Tibetan Plateau Research, Chinese Academy of Sciences,Beijing 100101, P.R. China
[3]Department of Chemistry, University of Karachi, University Road, Karachi, Pakistan

*Email: suhaibfarhan@yahoo.com

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Abstract: The temporal mapping of seasonal snow cover is generally being delineated through low resolution MODIS data (250-500m resolution) due to daily frequency of image acquisition; however, it sometimes compromises the mapping accuracies. In this study, the time-series of high resolution satellite imagery was used to evaluate the spatio-temporal changes in the snow covered area of Astore basin during summer and winter seasons from 1990 to 2017. The Object Based Image Analysis (OBIA) technique was applied on multi-spectral images of Landsat (TM and OLI sensors) of respective years (1990, 2000, 2010 and 2017) in order to discriminate the snow covered area in both seasons. Although OBIA is a strong technique that has been successfully applied in numerous research problems of remote sensing regarding cryosphere, but due to hindrances (i.e. Clouds and haze), it is sometimes not highly efficient to detect the snow accurately, therefore, Normalized Difference Snow Index (NDSI) has been calculated to distinguish snow covered area from snow free areas. The range of 0.4-1.0 was used as a threshold value for fuzzy membership function in OBIA to delineate the snow cover more precisely. The study suggested that the snow covered area is gradually increasing in winters during past few decades in the basin; however, in summer season as compared to winters, no specific trend has been observed.

Keywords: Snow covers, spatio-temporal, Fuzzy membership function, object based image analysis, Landsat.

Introduction

Snow is a great resource of fresh water in many countries particularly in northern hemisphere. Over 40% of the northern hemisphere is blanketed with seasonal snow (Klein et al., 1997). Snow cover change is a locally pervasive and globally significant ecological trend.

Both globally and regionally, the snow cover plays an important role, as it reflects a huge portion of the insulation, therefore keeping the Earth's radiation budget in equilibrium (Jain et al., 2008, Klein et al., 2000, Zhao and Fernandes, 2009). Furthermore, on local scale, for local water availability, groundwater recharge and river run-off, snow cover plays a great role, particularly in middle and high latitudes (Akyürek and Şorman, 2002, Jain et al., 2008).

At regional and local scales, farmers, water resource managers and flood forecasters are significantly interested in knowing how much water is stored in snow and when it is going to melt. Locally, snow provides moisture to soil and vegetation. On a larger scale, runoff from melting snow feeds streams, dry regions and rivers that supply water for agriculture and cities. Knowing when and how quickly snow is going to melt is necessary for forecasting, if water from melted snow will soak into the ground or cause flooding.

During the past century the earth experiences significant warming because the average atmospheric temperature of the globe has increased gradually. Since 1906, according to climatologists the average global temperature increased from 0.6 to 0.9 °C due to an increase in the amount of greenhouse gases. This increase in atmospheric temperature is causing certain tragic changes over the globe. Worldwide, especially in Polar Regions, rapid melting of snow and ice represents it as one of the leading impacts of the temperature rise. Thus, it becomes significant to map snow covered areas for the prediction of floods as well as the unusual pattern of precipitation caused by the melting of ice and snow. Remote sensing provides the benefits of acquiring snow data like snow water equivalent and snow covered area to predict the snow-melt runoff in real time, which is an essential factor for a dynamic physical process like snow (Roshani et al., 2008). Different airborne remote sensing systems along with various satellites are used to monitor the snow covered area, in order to predict various disasters like flood, land-sliding, avalanche etc. To monitor the snow cover precisely, satellites with advance repetition rates are important for obtaining cloud free images (Roshani et al., 2008).

For the identification and mapping of snow cover, Hall et al. (1998) formulated the Normalized Difference Snow Index (NDSI) for the first time, using Green and SWIR wavelength. NDSI appears to be a very suitable spectral index to distinguish snow cover, because the combination of Green and SWIR wavelength has a strong difference in spectral reflectance of snow

The objective of this study was to evaluate the spatio-temporal changes in the snow covered area of Astore basin during summer and winter seasons from 1990 to 2017. In this study, the time-series of high resolution satellite imagery of Landsat was employed. The Object Based Image Analysis (OBIA) technique was applied on multi-spectral images of Landsat (TM and OLI sensors) of respective years (1990, 2000, 2010 and 2017) in order to discriminate the snow covered area in both seasons. OBIA is a strong technique that has been successfully applied in numerous research problems of remote sensing regarding cryosphere, but due to hindrances (i.e. clouds and haze) it is sometimes not highly efficient to detect the snow accurately, therefore, Normalized Difference Snow Index (NDSI) has also been calculated to distinguish snow covered areas from snow free areas.

The Astore basin was selected for this study, since it is located at the confluence of westerly and monsoon climate systems. The westerly and monsoonal precipitation delivers 78% and 22% of the total precipitation respectively. This contrast in part arises because the Astore station is located in the northwestern part of the Himalaya and the westerly system strengthens its flow from southeast to northwest, conversely, the monsoon weakens from southeast to northwest. The northern slopes receive more precipitation in the winter season as compared to the southern slopes, since the westerly circulation is the source. However, the situation is reversed in the summer season because the main source is monsoonal. Here it should be noted that since no isotope data are available for the UIB yet, therefore the source of moisture in the precipitation event is unknown, however, the winter and spring precipitation in the basin is generally referred as a result of westerly circulation, whereas summer precipitation is usually referred to monsoon.

Study Area

Collectively Himalaya-Karakorum-Hindukush forms the largest mountainous chain on the Earth and after the Polar regions, which hold the third largest ice reserves. This chain also contains a treasure of solid water, which melts in summer due to temperature and makes this precious resource available in rivers during times of need (Asad et al., 2016; Rasul et al., 2008).

The Astore basin is a part of high-altitude western Himalaya and is one of the sub-catchments of upper Indus basin which is situated in the eastern side of the Nanga Parbat mountain in Pakistan having the geographic extent ranges between 74º25'06"E - 75º14'16"E, 34º46'34"N - 35º38'38" N, with an elevation range from 1202-8126 masl and mean elevation of 3980 masl (Farhan et al., 2014) (Fig.1). Astore basin is temperate and suffers cold season throughout the year, except the months of July and August, in which the temperature rises up to 27 ºC. In winters (i.e. December to February), the temperature reduces further, usually up to -25 ºC due to northern winds blowing in this period (Fig.2). Whereas, the annual mean temperature is 8.4 ºC. There is no particular period of precipitation within the western Himalayas. It ranges from 150 mm to above 1000 mm at Astore and Skardu stations (Ul Hasson et al., 2016). Maximum precipitation is observed in February and least in November (Table 1). Late March or late April is the period for snow melting in Astore basin and near, all the snow is melted by the period of July–August. Subsequently on this date, most of the flow of Astore river, which flows through it, depends on glacier melting and summer precipitation because the minimum snow fall occurs in August (Farhan et al., 2015).

Table 1 Historical weather data of Astore region.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Avg. Temperature (°C)	-4.5	-3.4	1.9	8.3	12.7	17.6	20.4	20.1	15.8	10	4	-1.6
Min. Temperature (°C)	-8.7	-7.9	-2.3	3.4	6.9	11.4	14.4	14.3	9.7	3.8	-1.5	-5.9
Max. Temperature (°C)	-0.3	1.1	6.1	13.2	18.6	23.9	26.4	25.9	21.9	16.2	9.5	2.7
Precipitation / Rainfall (mm)	34	41	66	72	66	20	25	30	24	21	10	18

Source of climate data: https://en.climatedata.org/info/sources

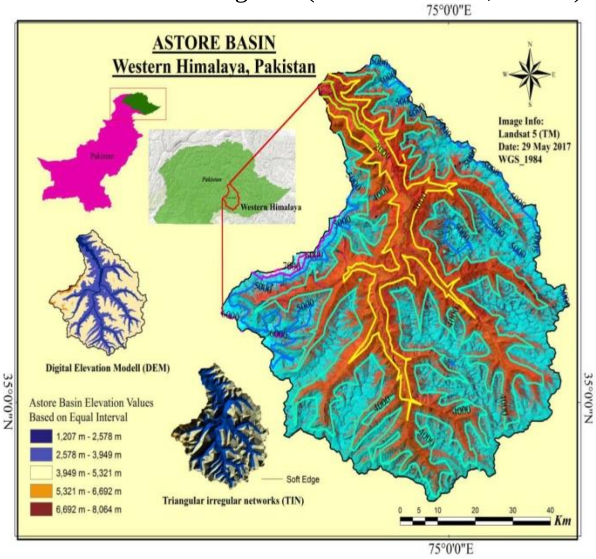

Fig. 1 Map of the location of study area of Astorebasin.

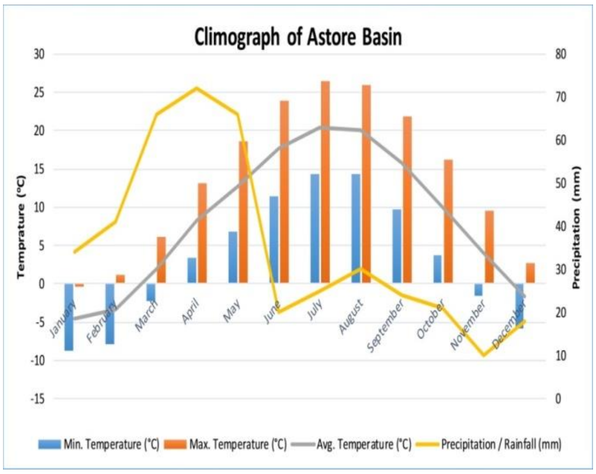

Fig. 2 Representation of annual minimum, mean and maximum temperature and rainfall of Astore basin.

Materials and Methods

This research is carried out to weigh up the variation in snow covered area in both winter and summer seasons from 1990 to 2017. A Satellite Remote Sensing (SRS) data can be classified through various supervised and unsupervised image classification techniques which can be used to discriminate snow cover extents. OBIAis another technique to map snow covered area, which is more reliable as compared to pixel-based image analysis because it considers spectral, textural and hierarchical info of objects, a group of neighboring pixels with relatable characteristics. OBIA makes segments from the objects and displays high performances by generating more accurate thematic maps (Mitri and Gitas, 2004).

Landsat provides ortho-rectified images and the study area of Astore basin gets covered in two scenes (with path/row 149/35 & 149/36) of Landsat, thus after layer staking, atmospheric correction followed by Geo-referencing (using the Datum WGS 1984 and the Universal Transverse Mercator (UTM) projection in a projected coordinate system) was executed. Subsequently after these operations, subset followed by mosaicking was extracted from full scenes for the development of area of interest (AOI). After deriving the subset, spectral index of NDSI was calculated. Using NDSI values as threshold, OBIA was performed to classify the images into two classes (snow covered area and others) in order to find the temporal changes from 1990 to 2017.

Using satellite images of different years freely downloaded from USGS archives at http://earthexplorer.usgs.gov/.In early 1960s, weekly maps of snow extent in the northern Hemisphere were prepared from satellite imagery(Table 2). Now, satellites provide daily maps of snow cover for both hemispheres. Ground observations, precipitation gauges, and weather stations with pressure-sensitive pillows measure the amount of snow on the ground and validate the satellite maps.

In this study, the spectral index of snow is calculated using the formula:

NDSI = (Green (0.55) - SWIR1 (1.60)) / (Green (0.55) + SWIR1 (1.60))

Table 2. Characteristics of data sets.

Date	Landsat Sensors	Path/Row	Spatial Resolution (m)
2/9/1990	TM	149/035	30
	TM	149/036	30
8/7/1990	TM	149/035	30
	TM	149/036	30
1/23/2000	TM	149/035	30
	TM	149/036	30
8/16/2000	TM	149/035	30
	TM	149/036	30
2/16/2009	TM	149/035	30
	TM	149/036	30
8/27/2009	TM	149/035	30
	TM	149/036	30
2/6/2017	OLI	149/035	30
	OLI	149/036	30
5/29/2017	OLI	149/035	30
	OLI	149/036	30

To distinguish snow covered area from non-snowy area on Landsat images, a range of 0.4-1.0 was obtained for snow covered area. This range was used as threshold for fuzzy membership function in OBIA. Initially, the segmentation process was applied on the image, subsequently by selecting Multi-resolution Segmentation algorithm to split the study area's subset into small homogeneous objects, based on spectral characteristics by adjusting different parameters like, image layer weight, scale parameter, shape and compactness.

Image layer weight includes different layers of Landsat image; we can give different weightage to desire layer for more accurate results. The scale parameter is unit-less, which assesses the maximum possible heterogeneity of image objects. User can define scale parameters based on the information level provided on the image. Small value of scale parameter will make small objects, whereas higher value will make larger objects. In this study, for segmentation process scale parameter was set to 100 because the subset of study area is not much bigger. Shape and compactness was set as 0.3 and 0.7 respectively. After executing the segmentation step, image was ready for the classification. Then a membership function classifier was executed. Membership functions permit users to specify the link between object values and the degree of membership to a class using fuzzy logic. Maximum and minimum values fix the upper and lower limits of this function (Trimble, 2011). A fuzzy set was established by membership function to determine objects' properties based on spectral and contextual info. Then, classification was performed on segmentation using Assign Class algorithm by giving a threshold value of NDSI $\geqq 0.4$ and NDSI < 0.4 in order to make different classes (snow covered area and others respectively) to discriminate the results.

Results and Discussion

The discrimination of snow cover areas for both winter and summer seasons were carried out by using satellite images. The assessment of snow cover areas is quite easy as compared to its evaluation using ground observations, since field measurements of remote and inaccessible areas are generally difficult.

The object based image classification (including multi-resolution segmentation and fuzzy membership function classifier), were performed by using a threshold value (0.4) extracted from the spectral index (NDSI), to differentiate snow and non-snowy areas.

After performing the classification and NDSI separately, a trend has been noticed that the area covered by snow gradually increased in winter season from 1990-2017 (Fig. 3), as mentioned in Table 3 i.e. the snow covered area in 1990 was 3579 sq. km, which increased up to 3579 sq.km in 2000, 3709 sq.km in 2009 and 3959 sq.km in the year 2017 respectively. All the above results were extracted from the satellite images of the months of January and February (i.e. winter season).

Table 3. Area statistics of both seasons produced from OBIA.

Time	Class	Area (Km^2)	Time	Class	Area (Km^2)
Feb 1990	Others	185	Aug 1990	Others	3004
	Snow Cover	3506		Snow Cover	831
Jan 2000	Others	99	Aug 2000	Others	3364
	Snow Cover	3579		Snow Cover	537
Feb 2009	Others	68	Aug 2009	Others	2932
	Snow Cover	3709		Snow Cover	940
Feb 2017	Others	33	Aug 2017	Others	3663
	Snow Cover	3959		Snow Cover	322

However, in summer season as compared to winters, no specific trend has been observed, but if we exclude the year 2009, the snow covered area is found to be decreasing (Fig. 4). As again mentioned in Table 3, the snow covered area was reduced in 1990 from 3506 sq.km in winter to 831 sq.kmin summer. Similarly in the years 2000, 2009 and 2017, the snow covered area in winters was reduced up to 537, 940 and 322 sq.kmrespectively in summers. These results were extracted from the satellite images of months of August (i.e. summer season).

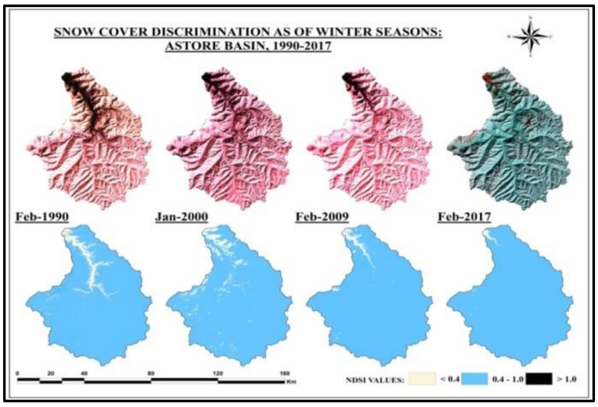

Fig. 3 Map showing the NDSI values for Landsat images of winter season from the year 1990 to 2017.

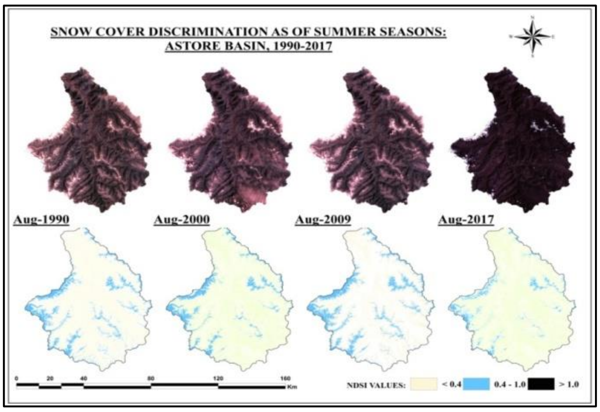

Fig. 4 Map showing the NDSI values for Landsat images of summer season from the year 1990 to 2017.

Similarly, the contributions made by OBIA can be seen in Figures 5 and 6. It is found that from 1990 to 2017, in winter seasons, snow covered area is increasing from 88 to 99% respectively. It means that the rate of precipitation in terms of snowfall is increasing, whereas in summer seasons, by excluding the plot of 2009 the snow covered area decreased from 20 to 8%, which means that the rate of snow melting is increasing with respect to time (Table 4).

Table 4. Snow covered area.

Year	Percentage in Winter	Percentage in Summer
1990	88.80%	20.82%
2000	89.70%	13.45%
2009	92.90%	23.55%
2017	99.10%	8.07%

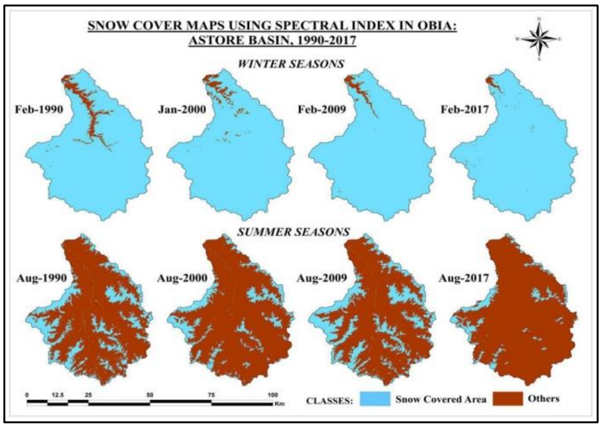

Fig. 5 Map showing the results of OBIA Landsat images of both winter andsummerfrom the year 1990 to 2017.

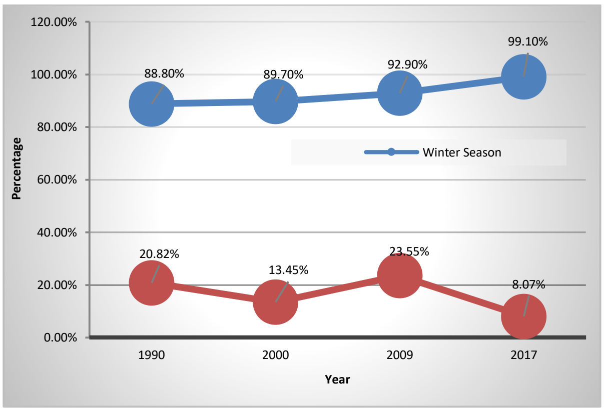

Fig. 6 Graphical representation of percent snow covered area in both winter and summer season from the year 1990 to 2017.

Conclusion

Around 1/3rd of global land surface is covered by seasonal snow for some part of the year. The bright white covering affects global conditions by reflecting solar energy distant from surfaces that would otherwise absorb it. Consequently, the earlier decrease in snow-cover extents increases the amount of solar energy absorbed by the land, and in turn, surface temperatures. Inspite of many advances in climate science, large uncertainty remains concerning with regard to the interactions between changes in the climate system as a whole, and changes in seasonal snow cover and glaciers. Notwithstanding, the snow cover mapping and estimation of other hydrological parameters through satellite imagery also play a very vital role in remote and inaccessible areas like mountainous and glaciated regions. The temporal mapping of seasonal snow cover is generally being conducted by employing low resolution MODIS data due to very high frequency of image acquisition i.e. twice a day, but it sometimes compromises the mapping accuracies. A time-series of high resolution satellite imagery was employed to evaluate the spatio-temporal changes in the snow covered area of Astore basin during summer and winter seasons from 1990 to 2017. Almost all of the area of Astore basin is covered by seasonal snow excluding the area below 2,500 masl. There is not much spatial variation in snow cover extents in the basin. The snow cover extent is mainly dependent on the elevation of the area. More than 2500 masl area is always covered by seasonal snow in winter and spring months during 2002 to 2015.

The OBIAtechnique was applied on multi-spectral images of Landsat time-series. The NDSI has also been calculated to distinguish snow covered area from snow free areas in order to accurately map seasonal snow cover extents. It is struggled that the snow covered area is gradually increasing in winters during past few decades in the basin. However, in summer season as compared to winters, no specific trend has been observed. This study provides a quantitative estimate of the snow-cover changes, including their role in climate change in the past. This will contribute to reduced uncertainty in future projections for water resource management, sustainable development and planning.

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