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MAPPING SNOW COVER FROM LANDSAT TM DATA USING NORMALIZED DIFFERENCE SNOW INDEX IN ALAKNANDA WATERSHED, GARHWAL HIMALAYA, INDIA

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Abstract

In this paper efforts have been made to monitor and measure the snow cover in Alaknanda watershed, Garhwal Himalaya, India using Landsat TM data. Landsat satellite TM data of two different time periods, i.e., 1990 and 2010 were used to quantify the snow cover changes over a period of 20 years. Both images of study area were processed using Normalized Difference Snow Index (NDSI) algorithm in ERDAS Imagine 9.3. ArcGIS 9.3 package was used to generate elevation and snow line information. The images of study area were classified into two classes, viz. snow cover and non-snow cover. The four sub-classes of snow cover i.e. frost, fine granular, medium granular and course granular were also mapped for the year 1990 and 2010. The results indicate that during the observation period, the snow cover decreased by 190 km^2 (27.10 %) and the snow line shifted upward from 5067 meters to 5275 meters (total 208 meters) at a rate of 20.80 meters per year. The study also reveals that, the area under frost and fine granular snow cover decreased by 66.03 km^2 and 151.03 km^2, respectively, while medium granular and coarse granular snow cover area increased by 32.69 km^2 and 0.86 km^2, respectively. The study highlights the usefulness of satellite data and NDSI techniques in snow cover mapping and monitoring. This research also attracts the attention towards the effect of global warming and need of sustainable watershed management in the study area.

Introduction

In recent years, a great deal of attention has been paid to monitoring and mapping of snow cover and snow line especially in Himalayan region. The Himalayas has one of the largest concentrations of glaciers and permanent snowfields outside the polar region and accounts for about seventy per cent of the non-polar glaciers (Kaur et al., 2009). The Himalayan region is now popularly known as the 'third pole', as the seasonal snow cover and permanent ice fields of its glaciers are the largest outside the polar region (Aggarwal et al., 2014). This region is the source of ten major rivers which are fed by the melting of snow and glaciers of this region and more than three billion people are benefitted by the food and energy produced in these river basins. Several perennial rivers are fed by snowmelt and glacier melt run-off in this region. The runoff available by snow/glacier melt exerts an influence on hydropower generation system, water management, strategic planning and many other developmental activities in any region. In addition, the snow cover itself is a surface condition that affects the Earth's radiation balance (Cohen and Entekhabi, 2001; Douville and Royer, 1996; Foster et al., 1996; Stieglitz et al. 2001; Yang et al., 1999). During the 20th century, a huge increase in global temperature was observed due to concentration of pollutants in the atmosphere and by 2100, the global surface temperature is projected to increase by 1.4–5.8°C. Several studies on Himalyan region have reported increasing trend of air temperature (Bhutiyani, 1999; Kulkarni et al., 2002, 2005; Kulkarni, 2007; Bhutiyani et al., 2008). Recently, research has reported an alarmingly depletion of snow cover and glacier melt in Himalayas (Dobhal, 2004; Kulkarni, 2007; Kulkarni et al., 2011) and their possible disappearance by the year 2035 (Cruz, 2007). For the scientific research and modeling in the fields of global warming, climatic change, hydrological cycle and environmental management, the reliable and updated information in time and space about vast snow covered areas are crucial. The information about the extent of the snow cover is most valuable because, it provides insight about the amount of water to be expected from snowmelt available for runoff and water supply (Salomonson and Appel, 2004). Such types of information are also valuable in hydropower generation system, water management, strategic planning and many other developmental activities in the region. Despite this, the reliable and updated spatio-temporal information on snow cover and glaciers remain a challenge in Himalayan region due to inaccessibility and only few ground observation sites.

In recent years, remote sensing (RS) and geographic information system (GIS) techniques have emerged as a popular viable substitute for real-time, year-round and large spatial coverage for monitoring over vast, rugged and remote areas (Konig et al., 2001; Hall et al., 2005). A variety of satellite imaging systems as well as several image processing techniques have been developed in last four decades to process and analyze RS images and extract meaningful information on snow cover and glaciers. These technologies facilitate fast and efficient methods to analyze, visualize and report the seasonal snow-cover changes (Kaur et al., 2009). For Himalayan region, several scholars have used satellite data acquired by numerous satellite sensors for snow-cover monitoring (Kulkarni and Rathore, 2003). The medium resolution satellite sensors of Landsat MSS and TM have been used in different studies for the mapping of snow cover area over drainage basins (Dozier et al., 1981; Dozier, 1984, 1989; Choi and Bindschadler, 2004; Erdenetuya et al., 2006) and concluded that the Landsat satellite imagery was of sufficient quality to monitor the snow cover area accurately. Conventionally, various mapping techniques such as manual delineation of snow cover boundaries, segmentation of ratio images and hard or crisp classification were used (Negi et al., 2009). Other analyzing techniques such as visual hybrid have also been used to estimate the areal extent of snow cover (Kulkarni and Rathore, 2003). The major difficulties in monitoring snow cover using remote sensing techniques in Himalayan region are the mountain shadow and confusing signature of snow and cloud in the visible and near-infrared region. Some researchers have introduced the reflectance ratio/index approaches to remove the effects of radiometric errors due to changing effects in the atmosphere and topographical changes across the scene. To address this issue, a spectral band ratio technique i.e., NDSI ((Tucker, 1979, 1986; Townshend and Tucker, 1984) has been used successfully for snow cover mapping (Hall et al., 1995, 2002, Kulkarni et al. 2002, 2006; Gupta et al., 2005) that takes advantage of the spectral differences of snow in short-wave infrared (SWIR) and visible spectral bands (green) to identify snow versus other features in a scene (Nolin and Liang, 2000). This is an effective index for mapping snow cover under rugged terrain and mountain shadow (Hall et al., 1995; Kulkarni et al., 2006). Therefore, in the present study snow cover mapping, monitoring and change detection were carried out in Alaknanda watershed, Uttarakhand (India) using Landsat TM data and NDSI model in GIS environment.

Objectives

The main objectives of the study are-

- To map snow cover and snow line in Alaknanda watershed using RS and GIS techniques.
- To analyze snow cover changes and snow line shifting by comparing TM images of year 1990 and 2010.
- To examine the spatio-temporal dynamics of snow cover during 1990 to 2010.

Study Area

The study area, Alaknanda watershed, is situated in Garhwal Himalaya of Uttrakhand and located within geographical coordinates of 30º10'7" North to 31º04'21" North latitude and 78º36'17" East to 79º46'55" East longitudes and encompasses an area of 4548 km² (Fig. 1). The altitude of the watershed varies from 577 to 6663 meter. The river Alaknanda rises at the confluence and feet of the Satopanth and Bhagirathi Kharak glaciers in Uttarakhand. It meets the Bhagirathi River at Devprayag after flowing for approximately 190 km through the Alaknanda valley. Its main tributaries are the Mandakini, Nandakini, and Pindar rivers. The Alaknanda system drains parts of Chamoli, Tehri, and Pauri districts. The study area characterized by glacio-fluvial activity, but the upper portion of the watershed is dominated by glacial processes (Selvan et al., 2014). Climatically, this area falls in the temperate monsoonal zone. Maximum temperature ranges between 30°C to 36°C while minimum temperature varies between 0° C to 6°C. The Alaknanda watershed experiences strong climatic seasonal variations, which is clearly reflected in the monthly variations in stream flows. Maximum flow takes place during June-September, when both rainfall and rate of snow melt are at maximum.

Materials and Methods

Database

Data used in this study are: (i) Landsat V Thematic Mapper (TM), Multi-spectral image (acquired on October 15, 1990 and October 11, 2010 with 30 meter spatial resolution, path/row 145/38 (source: http://glcf.umiacs.umd.edu). (ii). Shuttle Radar Topography Mission (SRTM) digital elevation dataset for elevation data (source: http://glcf.umiacs.umd.edu) (iii) Google Earth high resolution images (source: http://www.google earth.com) (iv) Survey of India topographic map at 1:50000 scale (v) Arc GIS 9.3 (ESRI) and ERDAS Imagine 9.3 (Leica Geosystems, Atlanta, U.S.A.) packages.

Research Methodology

The base map of study area was prepared in the ArcGIS 9.3 software by using the survey of India topo sheets at the scale of 1:50,000 and then watershed boundary was checked and corrected by superimposing the DEM (Digital elevation model) data derived from the SRTM digital elevation dataset with 90 m spatial resolution and ± 15 m vertical

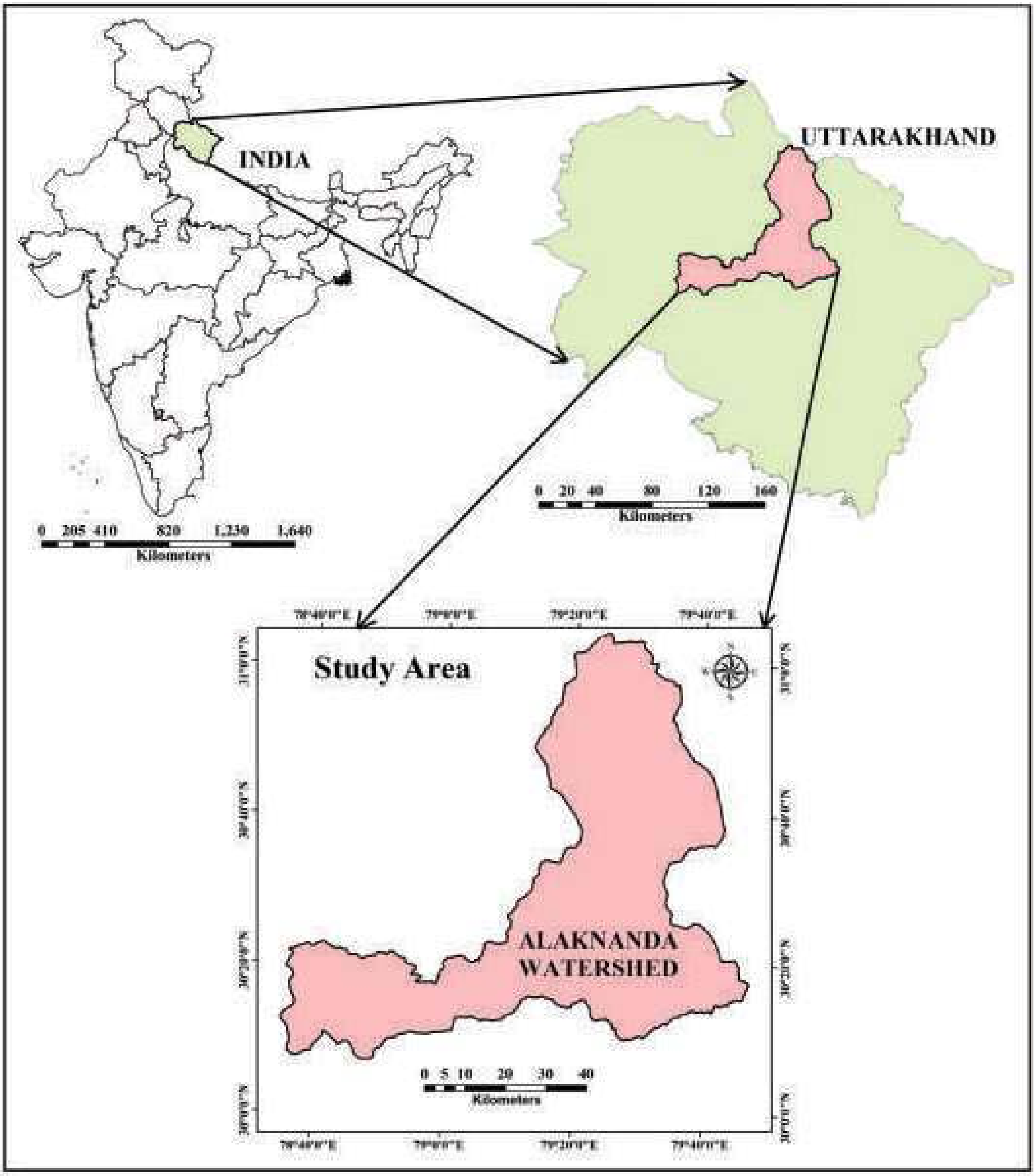


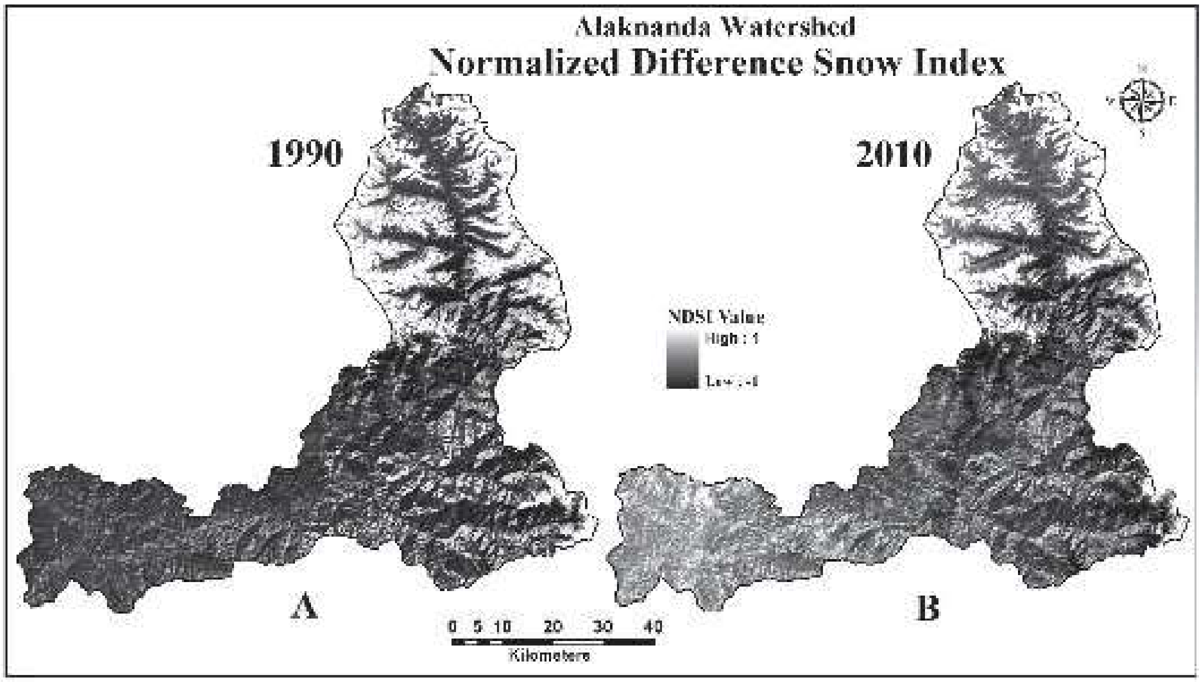
Fig. 1

accuracy. A rectification has been done in Landsat V TM images using the ArcGIS 9.3 software and the images have been given the base map coordinates (i.e. UTM projection, and 44 N zone) for the purpose to identify the study area in the image. To study the spatial and temporal pattern of snow cover and snow lines in the watershed, a set of two Landsat V TM images were procured in digital format for the years 1990 and 2010. Landsat V TM (band 2: 0.52-0.60 μm; band 3: 0.63-0.69 μm; band 4: 0.76-0.90 μm and band 5: 1.55-1.75 μm) with spatial resolution of 30 meter were stacked through Global Land Cover Network (GLCF). To interpret shadowed area in the hilly terrain, false colour composite image were created by using 2, 3 and 4 bands. The Landsat data set provided by Global Land Cover Network were radiometrically and geometrically (ortho-rectified with UTM/WGS 84 projection) corrected. The digital numbers (DNs) of geo-referenced images were converted into reflectance. Since Landsat images were used, this conversion was done in ERDAS Imagine 9.1 according to the methods outlined in the Landsat V data users Handbook. This involves conversion of DNs into the radiance values, known as sensor calibration, and then estimation of reflectance from these radiance values (Kulkarni et al. 2002). Since the gain on each of these Landsat channels can vary from high to low between successive overpasses, it is essential to convert apparent digital number to reflectance for consistency between different images. To separate the snow covered from non-snow covered area NDSI was estimated for the both TM images of 1990 and 2010 using the following equation (Hall et al., 2002):

NDSI = (TM Band 2 – TM Band 5) / (TM Band 2 + TM Band 5)

where, TM Band 2 and TM Band 5 are the reflectance of the green and shortwave infrared bands, respectively.

Furthermore, Alaknanda watershed was clipped using its shape file from NDSI image. This task was performed in ERADS IMAGINE 9.1 software, by superimposing shape file over NDSI image and selected the shape file as the area of interest by AOI tool and subset by viewer method. The NDSI clipped raster data of the years 1990 and 2010 were then reclassified into two classes i.e. snow cover and non-snow cover area in Arc-GIS 9.3 software, by using the Spatial Analyst tool. To segregate the snow covered from non-snow covered area, Hall et al. (1998) suggested a NDSI threshold of >0.40 be used to map snow cover. After displaying the NDSI imagery on the screen of Arc map, the lower limit of snow cover in the watershed area was digitized for both years. By superimposing the lower limit of snow cover of both years, the area of change from snow cover area to non-snow cover area was worked out. The study area NDSI image has been further classified by using reclassify option of ArcGIS into four snow cover categories based on the threshold value suggested by Hall et al. (1998, 1995) namely coarse granular snow ranging between 1 to 0.937, medium granular snow 0.937 to 0.848, fine granular snow 0.848 to 0.611 and frost 0.611 to 0.414. This step was performed in ArcGIS 9.3 software, in which the NDSI images were reclassified in 'Spatial Analyst toolbar' entering threshold values. The NDSI reclassified four categories raster image i.e. coarse granular snow, medium granular snow, fine granular snow and frost were then converted into vector based polygon format for the estimation of total snow cover area and to know about the area falling within each category of snow cover. In order to draw snow line, a shape file was created in ArcGIS 9.3 software 'Arc catalogue' and snow line has been digitized for the year 1990 at the scale of 1:20,000. In order to draw snow line for the year 2010 the same shape file (i.e. year 1990) has been copied into another folder and through ArcMap editor reshape task, the reduced upper limit of snow cover area was digitized keeping the map scale at 1:20,000. To estimate snow line height, the snow line of both years were overlaid on the DEM data and then a point shape file has been created in Arc-catalogue and keeping the snapping mode on, the digitization was done, over the snowline of one year i.e. 1990 and then the digitized points were



Source: Landsat TM Imagery

Fig. 2

masked by the mask function from DEM data, so, that each point bear some heights and then those points were exported into the Microsoft excel sheet and the average height have been estimated. The same process was repeated for the year 2010 snow line height estimation.

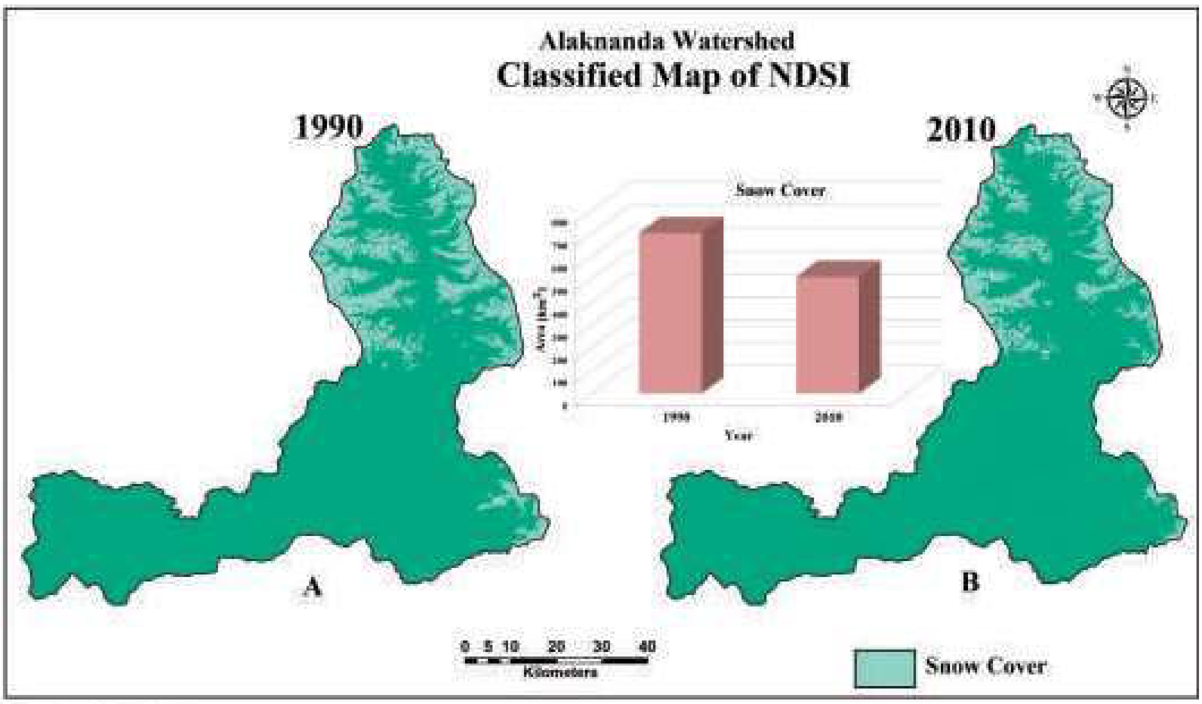
Results and Discussion

NDSI Analysis

In the present study the spatio-temporal pattern of snow cover in Alaknanda watershed, a set of two TM images were analyzed using NDSI model in ERDAS Imagine 9.3 Software. Initially, the DNs of the seven-band of TM images were processed and converted into extra-atmospheric reflectance values (reflectance above the atmosphere), using the published Landsat TM post-launch gains and offsets (ENVI software version 3.2). The resultant reflectance images were then used for NDSI estimation. NDSI was calculated on a pixel-by-pixel basis and generated gray scale images with high values (bright pixels) representing snow. The results obtained through this analysis are diagrammatically illustrated in Fig. 2 which depicts the distribution of NDSI variation in year 1990 and 2010 in the study area. Pixel values in the resultant NDSI images vary between 1 to -1. On the basis of threshold value of 0.40, both NDSI images were classified to map out the snow cover (i.e. if NDSI > 0.40 pixel is snow, else not snow).

Spatial Dynamics of Snow Cover

Fig. 3 depicts spatial distribution of snow cover area in 1990 and 2010 in the study area. The calculation of area under snow cover during the years 1990 and 2010 were worked out and presented in Table 1. It reveals that the snow cover in Alaknanda watershed was found as 15.51 per cent (701 km^2) of entire watershed in 1990 while it turned about 11.30 per cent (511 km^2) in 2010. The snow cover area in the Alaknanda watershed has depleted



Source : Landsat TM Imagery

Fig. 3

Table 1
Alaknanda Watershed : A Comparison of Snow Cover during 1990 and 2010

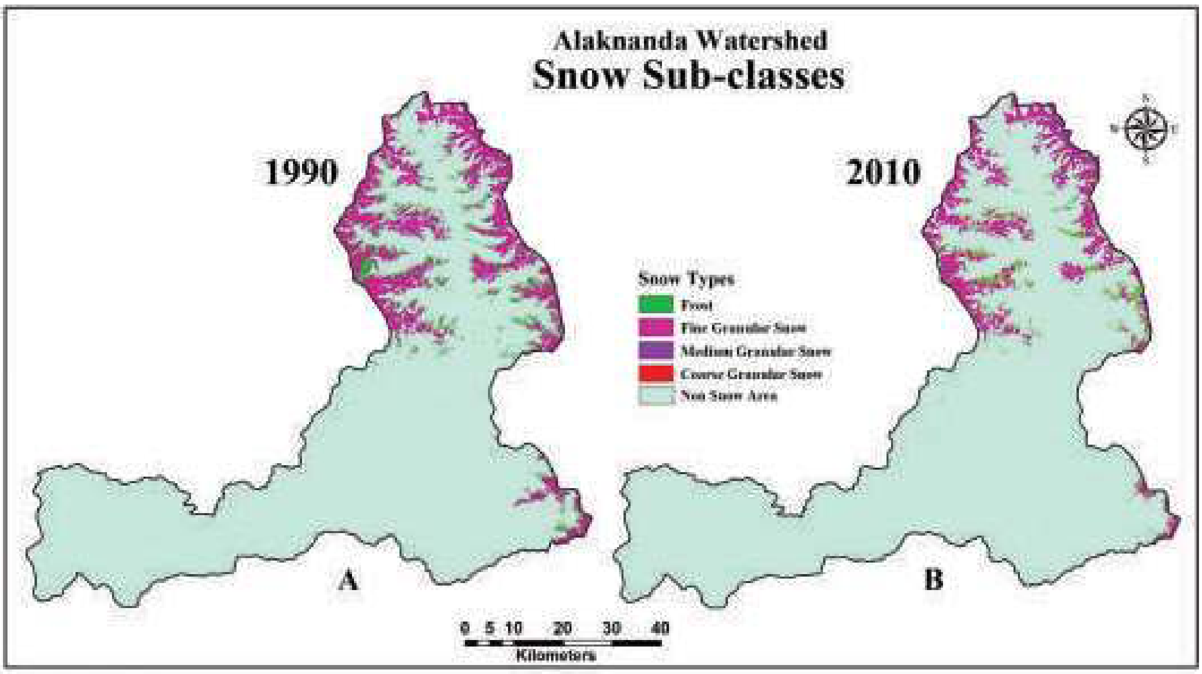
Year	Snow Cover	
	(km²)	(Per cent)
1990	701	15.51
2010	511	11.30
Change (1990-2010)	190	4.21

Source: Landsat TM Imagery

Table 2
Alaknanda Watershed : Snow Cover Classes and Change Detection (1990 -2010)

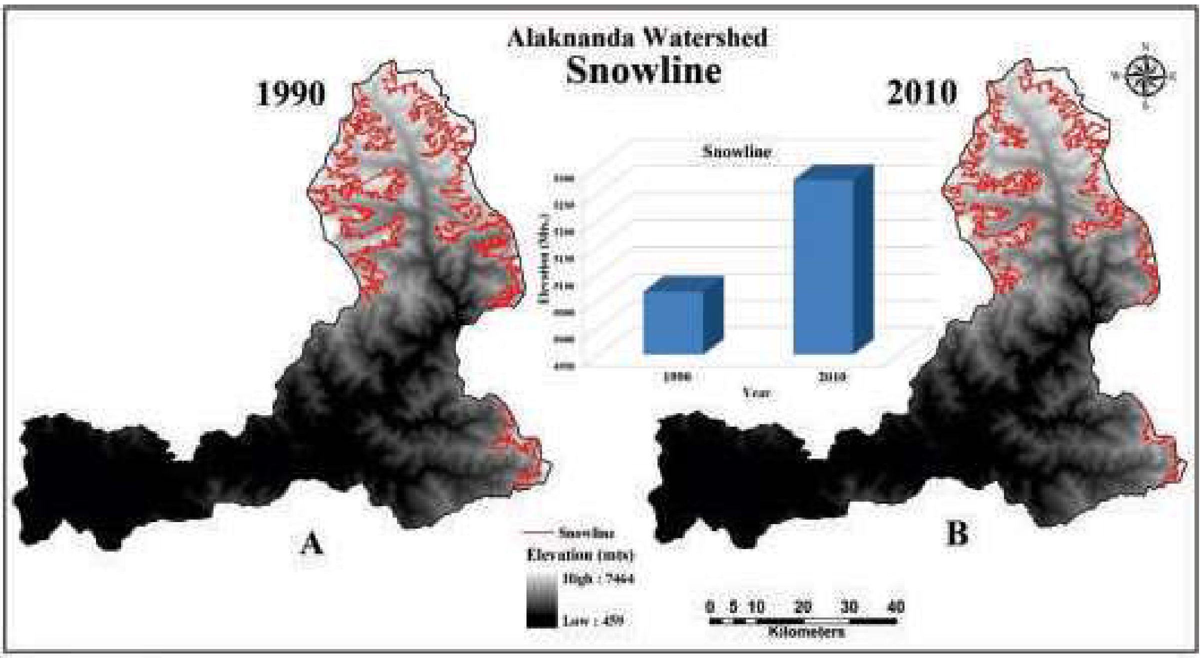
Snow Cover Classes	NDSI	1990		2010		Change (1990-2010)
		Snow Area		Snow Area		Snow Area
		(km²)	(Per cent)	(km²)	(Per cent)	(km²)
Frost	0.414	203.85	29.08	137.82	26.97	-66.03
Fine granular	0.611	489.28	69.79	338.25	66.19	-151.05
Medium granular	0.848	7.56	1.07	33.76	6.60	32.69
Coarse granular	0.937	0.31	0.04	1.17	0.22	0.86

Source: Landsat TM Imagery



Source : Landsat TM Imagery

Fig. 4



Source : Landsat TM Imagery

Fig. 5

considerably during the study period (1990 to 2010). During this period, about 190 km^2 snow cover of the Alaknanda watershed has been converted into non-snow cover area at an average rate of 9.50 km^2/year.

Snow Cover Types

Fig. 4 and Table 2 reveal that about 203.85 km^2 (29.08 % of total snow area) area was covered by frost snow, while 489.28 km^2 (69.79 % of total snow area) was found under granular snow cover during 1990. The medium granular and coarse granular snow were observed on 7.56 km^2 (1.07 % of total snow area) and 0.31 km^2 (0.04 % of total snow area), respectively. In 2010, the frost snow was found on 137.82 km^2 (26.97 % of total snow area), while the fine granular snow cover was observed on 338.25 km^2 (66.19 % of total snow covers). The medium and coarse granular snow cover were mapped on 33.76 km^2 (6.60 % cover in total area) and 1.17 km^2 (0.22% of total snow cover), respectively. The analysis reveals that both positive and negative changes occurred in the snow sub-classes cover pattern in the study area (Table 2). During the last twenty years (1990-2010), the frost snow and granular snow area decreased by about 66.03 km^2 and 151.05 km^2, respectively, whereas the medium and coarse granular snow cover increased to about 32.69 km^2 and 0.86 km^2, respectively.

Snowline Shifting

The analysis shows that average height of snowline in Alaknanda watershed was 5067 meters above the mean sea level during 1990 which subsequently shifted up to 5275 meters in 2010. Hence, the total shifting of snowline was about 208 meters, recording a depletion rate of 10.40 meters per year (Fig. 5). This shifting of the snow line in Alaknanda watershed may be attributed to global warming.

Conclusions

A periodical monitoring of snow cover through digital processing of satellite images of different dates may play a vital role in environmental planning and watershed management. It is evident from this study that the snow cover area is depleting steadily in the Alaknanda watershed. During the last two decades (1990-2010) about 190 km^2 area of the watershed has experienced depletion of snow cover, resulting decrease at an average rate of 9.50 km^2/year. In addition, the frost snow and granular snow area has also decreased by about 66.03 km^2 and 151.05 km^2, respectively, whereas the medium and coarse granular snow cover increased to about 32.69 km^2 and 0.86 km^2, respectively. Also, snow line has been shifted towards higher elevation and a shift of about 10.40 meter per year was observed. Depletion of snow cover and shifting of snow line in the watershed may be attributed to global warming. This continuous depletion of snow cover and shifting of snowline may result severe environmental degradation and ecological damages in Alaknanda watershed.

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