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## **Due to global warming: Snow line dynamics in the Gori Ganga watershed, Kumaun Himalaya by using RS & GIS**

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### **Abstract**

Present research paper is an attempt to examine the dynamics of snow line by using Normalized Difference Snow Index (NDSI) in Gori Ganga watershed, Kumaun Himalaya, Uttarakhand (India). For the study of detect snow line used of Landsat satellite imageries of three different time periods like Landsat TM of 1990, Landsat TM of 1999 and Landsat TM 2016. Geographical distribution of snow line average height reveals that in 1990 about 4665.02m, 1999 about 4764.97m and in 2016 about 5068.95m average height of the Gori Ganga watershed. These data suggest that due to global warming about 403.93m snow line average height of Gori Ganga watershed has been shifted into non-snow cover area at an average rate of 15.53m/year during 1990 to 2016.

**Keywords:** NDSI; snow line; dynamics; Kumaun Himalaya; remote sensing and GIS

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### **Introduction**

The snow line is the boundary which lies between snow covered area and snow free surface. The permanent snow line is that line above which snow will lies all over the year (Waugh, 2000). The actual snow line may adjust monthly as well as seasonally and be either significantly dynamically in elevation (Wikipedia, 2020). The final height of the snow line in the mountain at the end of the melting season is subject to climatic variability and therefore may be different from seasonally and year to year (Singh *et al.* 2011). Snow related maps derived from various satellite data are a pixel-based representation of a snow covered area and non-snow cover area with spatial resolution of a few hundred meters up to one kilometer, a pixel, either classified as 'snow' or 'no-snow', often consists of snow-covered and snow-free areas (Kleindienst *et al.* 2000). The snow line is measured using Remote Sensing sensors, automatic cameras, aerial photographs and satellite images, because the snow line can be established without on the ground measurements.

Snow line can be measured in remotely and very difficult to access snow surface area (Singh *et al.* 2011).

Satellite data monitoring and evaluate snow parameters at regional and global scale and the remote sensing techniques is being used extensively for snow cover monitoring with the help of various satellite images. Geographical Information System (GIS) along with Remote Sensing (RS) technology facilitate fast and efficient ways to analysis, visualize and presenting reports on the snow cover changes in whole year. On the satellite images, pixels are helping to identified snow by NDSI method from Advanced Wide Field Sensor (A WiFS) sensor using remote sensing and GIS techniques. NDSI method is very effectively detecting snow even under mountain shadow (pant, 2018).

The Himalayan glaciers, as noted above, are retreating at a faster rate than the global average.

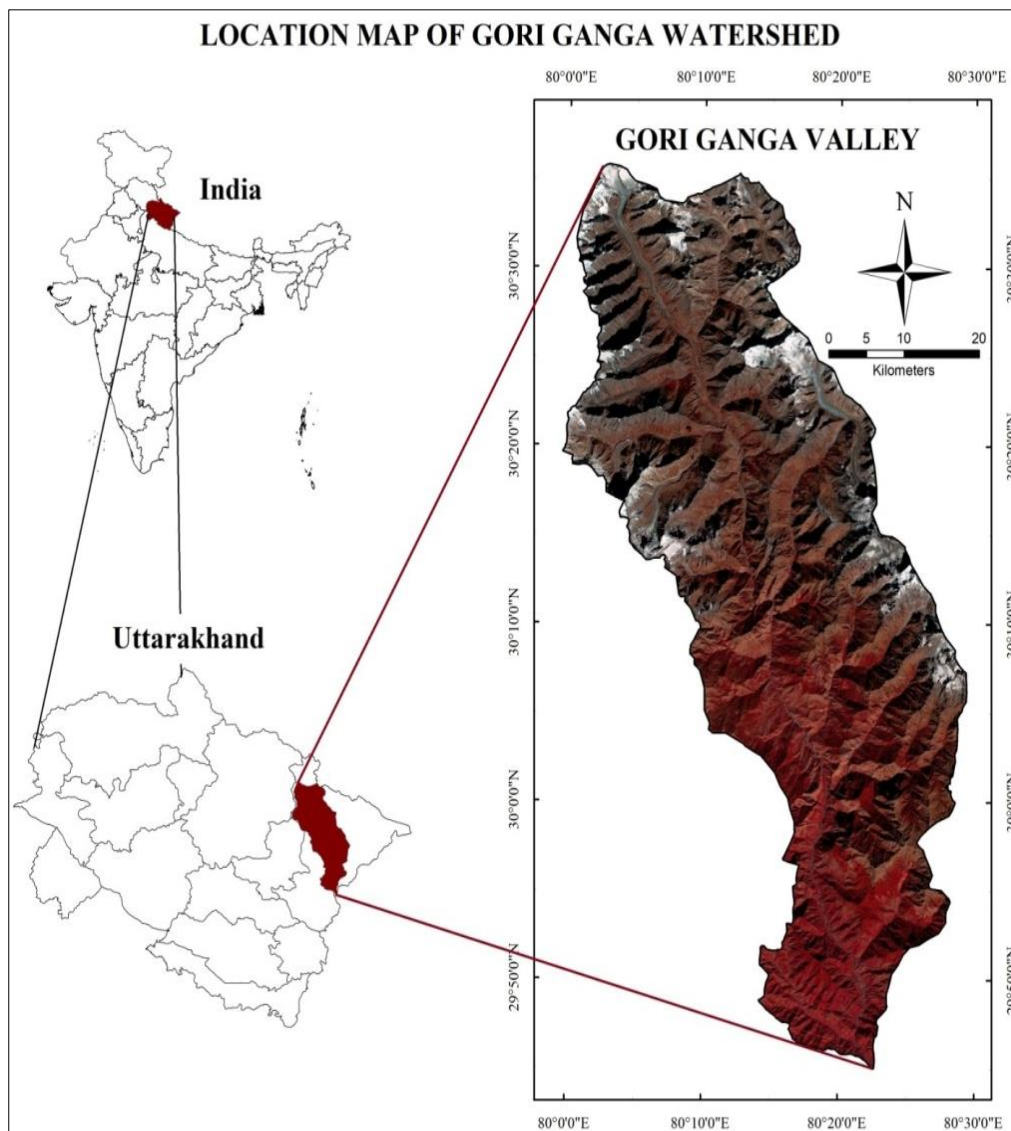
Advanced blooming, migration of species and changed timings of hibernation and breeding suggests that the climate in the Himalayan region is changing. The northward movement of species and tree line is also widely reported. An increased frequency and intensity of extreme weather events is also noted in the Himalayas. The impacts of climate change in Himalayas have local, regional and global implications. With the rapid development of highway/road, building construction, use of plastic materials, rapidly highly use of fuel in the Himalayan region. Present day Himalayan glacier melting rapidly because of effecting by global warming. If snow retreat in the valley, its effect on vegetation line and timberline. For all the condition applies in the study I found a watershed area in central Himalaya name of Gori Ganga watershed lies on district Pithoragarh.

Snow line height estimation the snow line of both the years have been overlaid on the Landsat-8 data and then a point shape file has been created in Arc-catalogue and keeping the snapping mode on, the digitization has been done, over the snow line of the years 1990, 1999, and 2016, then the digitized points were masked by the mask function from Landsat-8 data, so that each point bear some heights and then those points were exported into the Microsoft excel sheet and the average height has been estimated.

### **Study Area**

The study area, viz., the Gori Ganga watershed (Kumaun Himalaya) extends between 29°45'0''N to 30°35'47''N latitudes and 79°59'33''E to 80°29'25''E longitude, and encompasses an area of 2191.93 km<sup>2</sup> in Figure 1. The altitude of the Gori Ganga watershed varies between 626m and 6639m. The Gori Ganga watershed has 168 villages and total population is about 40616 (2011).

Gori Ganga watershed spreads in three blocks, i.e., Munsyari, Dharchula and Didihat.

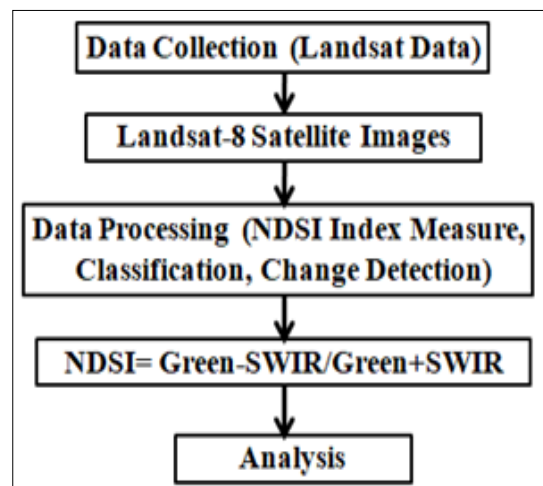


**Fig 1:** Location map of the study area, viz, Gori Ganga watershed.

### Methodology

For the work out with snow line average height, remotely sensed data are extremely valuable. To examine the snow line average height in the Gori Ganga watershed, Landsat satellite imageries of three different dates and years were acquired by Global Land Cover Facility (GLCF) and United States Geological Survey (USGS) Earth explorer. The first imagery used in the present study is Landsat TM of 18 November 1990 at 30 m resolution. The second imageries are of Landsat TM of 15 November 1999 at 30 m resolution and third imageries used for the present study is Landsat TM of 28 November 2016 at 30 m resolution. These imageries helped in understanding extend of snow line average height in the watershed over the last 26 years (i.e. 1990 to 2016). Figure 2 is presenting flowchart of methodology. Additionally, the reflectance of clouds remains high in SWIR band, thus NDSI allows in discriminating some clouds and snow. NDSI is useful for identification of snow and ice and for discriminating snow/ice from most cumulus clouds. This method is generally used for snow cover mapping using satellite data (Kulkarni *et al.* 2006; Gupta *et al.* 2005; Negi *et al.* 2008) [10, 5, 13]. NDSI is defined by following relation and it ranges from -1 to +1 (Kulkarni *et al.*,

2003) [8]. To handle the mixed area, the threshold value of NDSI was lowered from 0.4 to 0.1 (Klein *et al.* 1998) [7].



**Fig 2:** Flowchart of methodology

**Result and Discussion**

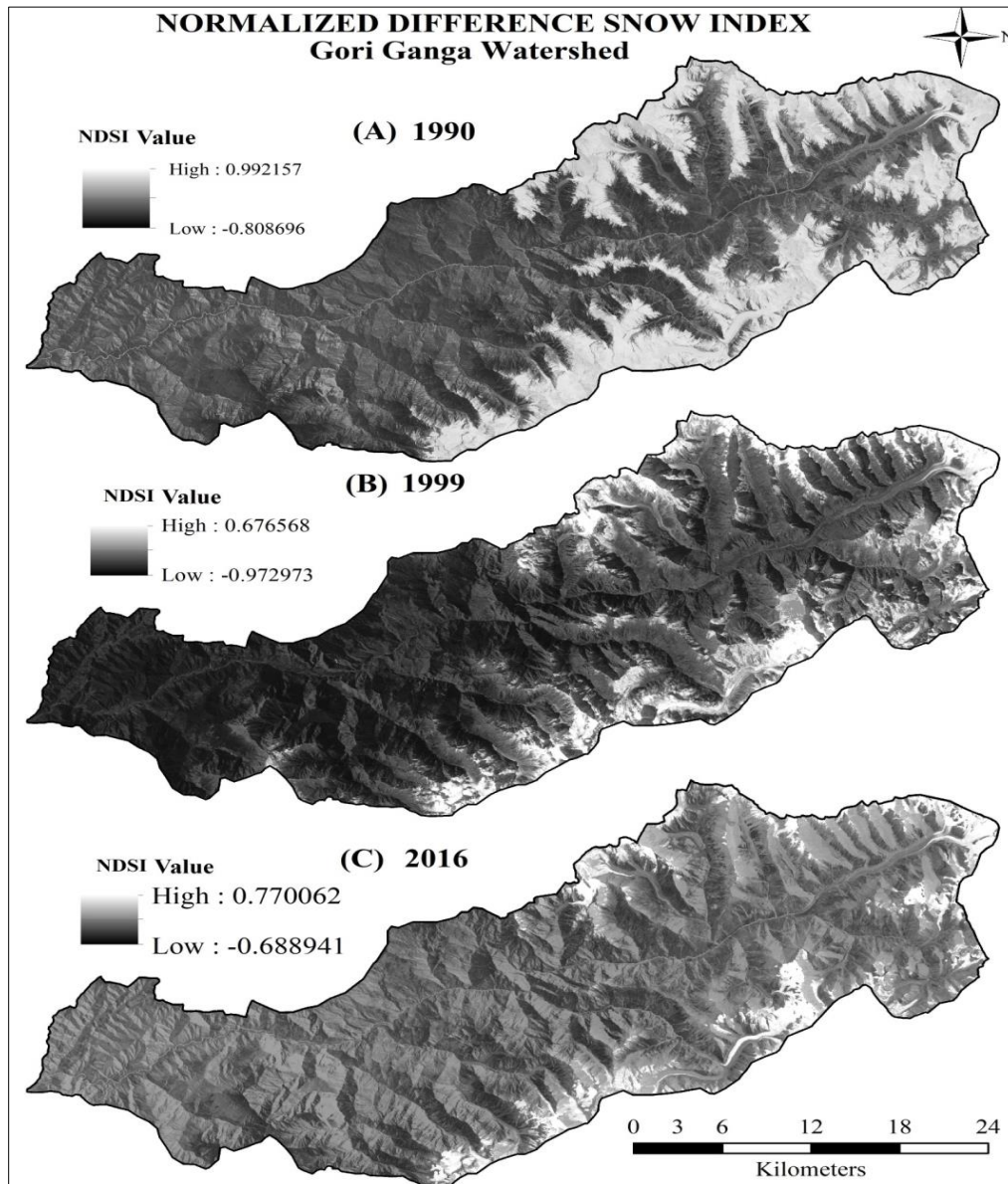
The results obtained through the analysis of NDSI imagery are diagrammatically illustrated in Figure 3 and are registered in Table 2. Figure 3 depicts distribution of NDSI variation while Figure 4 and 5 depicts geographical distribution of snow line average height in 1990, 1999 and 2016 in the study area. Figure 6 depicts snow line height frequency curve in 1990 to 2016 and Figure 7, 8 and 9 depicts dynamics of snow line average height in 1990 to 2016.

A brief account of these results it's discussed in

the following paragraphs.

**Normalized Difference Snow Index (NDSI)**

Uses of NDSI for the high and low reflection of snow in visible (Green) and Short Wave Infra Red (SWIR) region respectively and it can also delineate and map the snow in mountain shadows. Additionally, the reflectance of clouds remains high in SWIR band, thus NDSI allows in discriminating some clouds and snow. NDSI is defined by following relation and it ranges from -1 to +1 (Kulkarni *et al.*, 2002).



**Fig 3:** Normalized difference snow index map values (>0.4) in different years in the Gori Ganga watershed, (A) 1990, (B) 1999 and (C) 2016 (based on Landsat-8 satellite imageries).

$$NDSI = \frac{Green - SWIR (Short\ Wave\ Infra\ Red)}{Green + SWIR (Short\ Wave\ Infra\ Red)}$$

In the methodology describe for NDSI using landsat data. Using Arcgis software, take three different years (1990, 1999 and 2016) landsat data were taken for calculating NDSI index for Gori

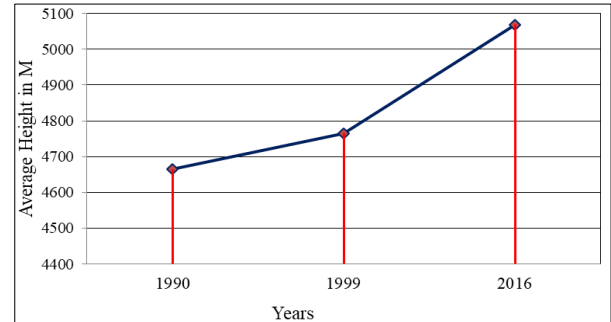
Ganga watershed. Use of threshold value for NDSI of 0.4 is defined for the imageries of different sensors (Xiao *et al.* 2001). To handle the mixed area, the threshold value of NDSI was lowered from 0.4 to 0.1 (Klein *et al.* 1998) [7]. Figure 3 is our come of NDSI which is based on Landsat-8 satellite imageries of three different time periods, i.e., Landsat TM of 1990, 1999 and 2016.

**Status and Estimation of Snow Line**

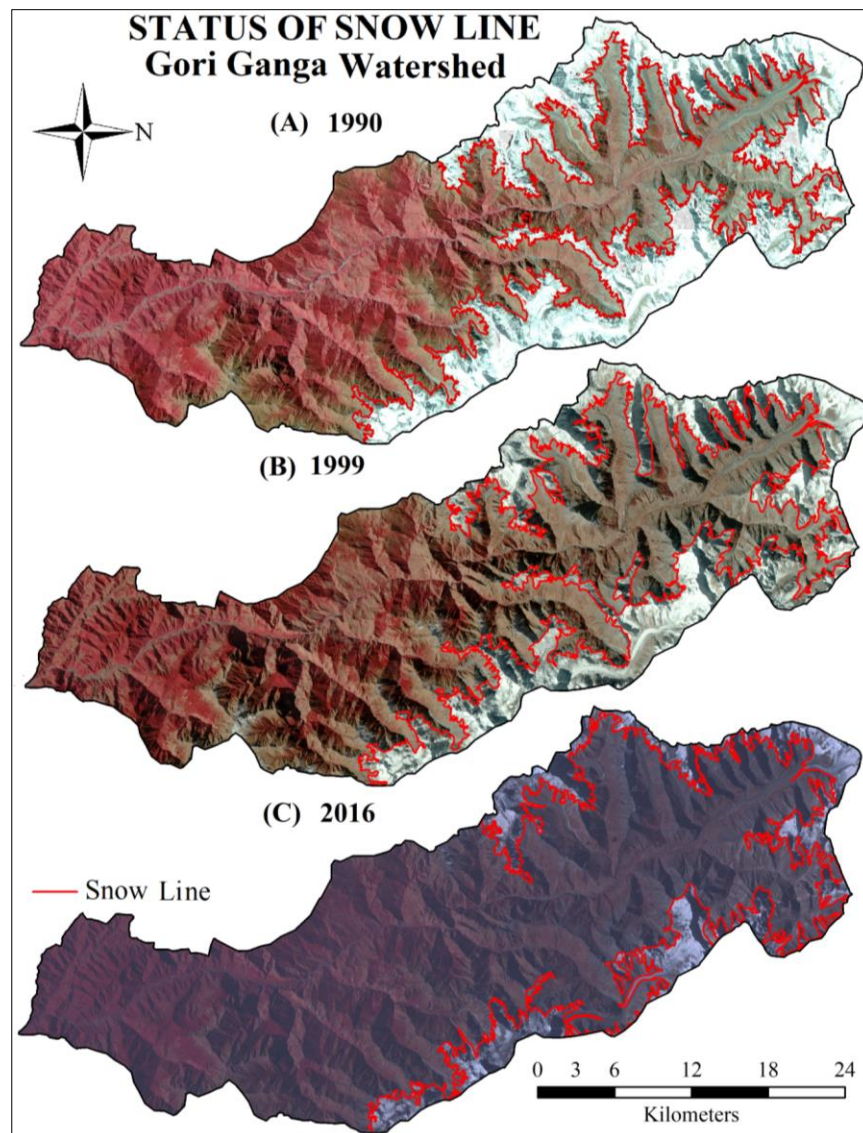
Snow line height estimation is an important aspect in the snow cover mapping. It reveals that how much snow cover has been reduced in the study area? And what is the current status of snow line in the study area? The methodology is as, firstly took landsat-8 data 1990, 1999 and 2016 and demarcated the snow line on these images. Then convert snow line into point feature using spatial analyst tool in Arc GIS and masked point feature into Cartosat-1 data. Obtaining value of different point used to analysis of different elevation height based on their elevation point average height of snow line for different years was worked out as presented in Table 1 and figure 4. These data reveal that the average height of snow line in Gori Ganga watershed was about 4665.02m in 1990, about 4764.97m in 1999 and about 5068.95m in 2016 (Table 1). Figure 5 (A), (B) and (C) depicts the geographical location of snowline of the Gori Ganga watershed in the year 1990, 1999 and 2016 which is based on the NDSI values. Figure 6 (A), (B) and (C) depicts the snow line height frequency curve in the Gori Ganga watershed in the year 1990, 1999 and 2016 which is based on Cartosat-1 data extract values.

**Table 1:** Average height of snow line in 1990, 1999 and 2016 in Gori Ganga watershed (based on Cartosat-1 satellite imageries).

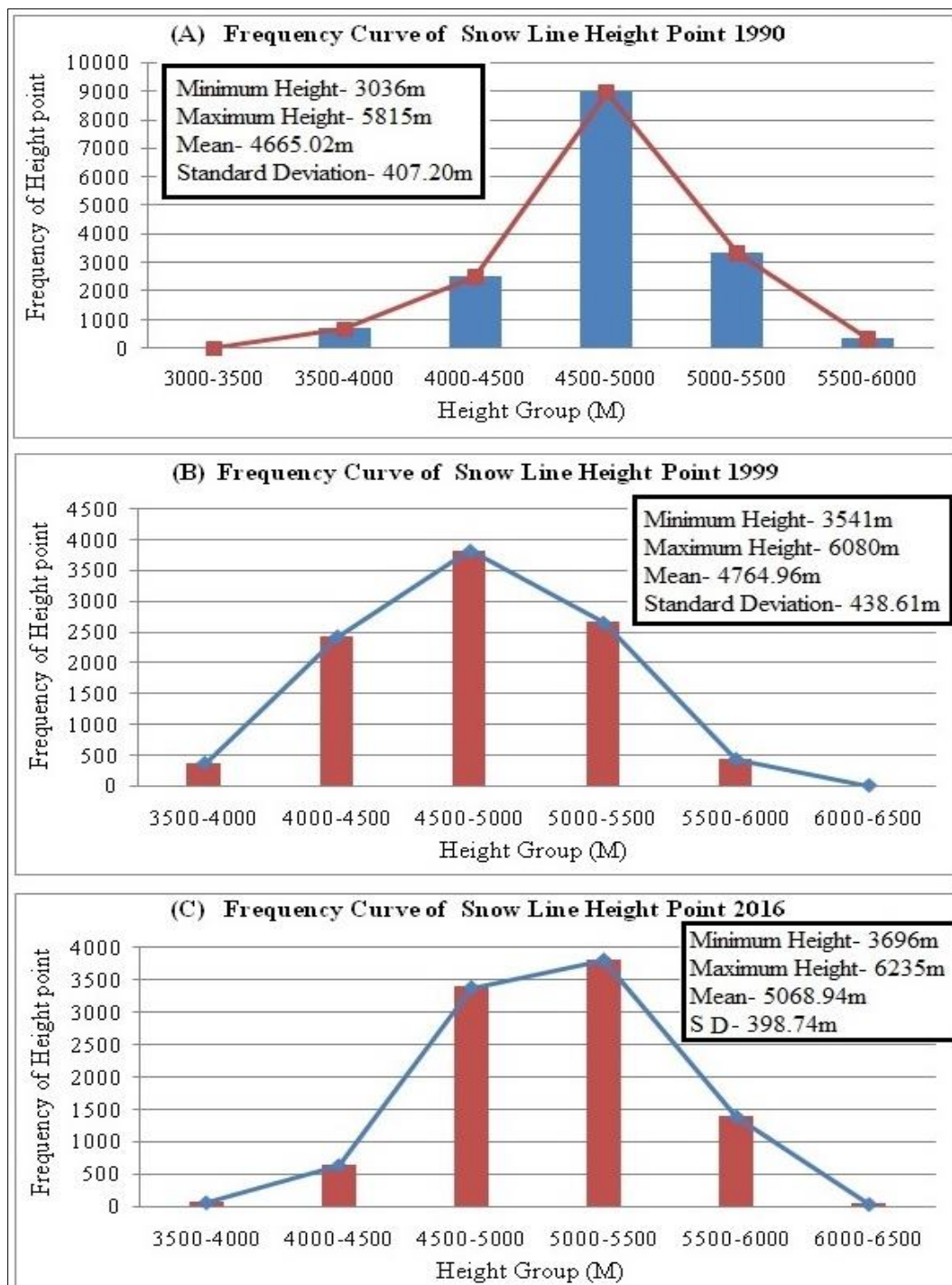
Years	Snow Line Average Height (m)
1990	4665.02 (Standard Deviation 407.20m)
1999	4764.97 (Standard Deviation 438.61m)
2016	5068.95 (Standard Deviation 398.74m)



**Fig 4:** Average snow line altitude for the year 1990, 1999 and 2016 (based on Cartosat-1 satellite imageries).



**Fig 5:** Geographic location of snow line based on NDSI values (>0.4) in different years in the Gori Ganga watershed (A) 1990, (B) 1999 and (C) 2016 (based on Landsat-8 satellite imageries).



**Fig 6:** Snow line height frequency curve in the Gori Ganga watershed (A) 1990, (B) 1999 and (C) 2016 (based on Cartosat-1 satellite image).

### Snow Line Height

The Snow line extracted for different years (i.e. 1990, 1999 and 2016) is depicted by Figure 7 A, B and C. to determine the average height of snow line in the study area. The DEM was overlaid on these snow Line maps and by taking maximum height of snow (at 15842 different places in 1990, 9675 places in 1999 and 9333 different places in 2016) throughout the Gori Ganga Watershed, the average height of snow line was worked out which is depicted in Figure 7 for different years. A brief description of Snow line of different years is presented in the following paragraphs.

### Snow Line in 1990

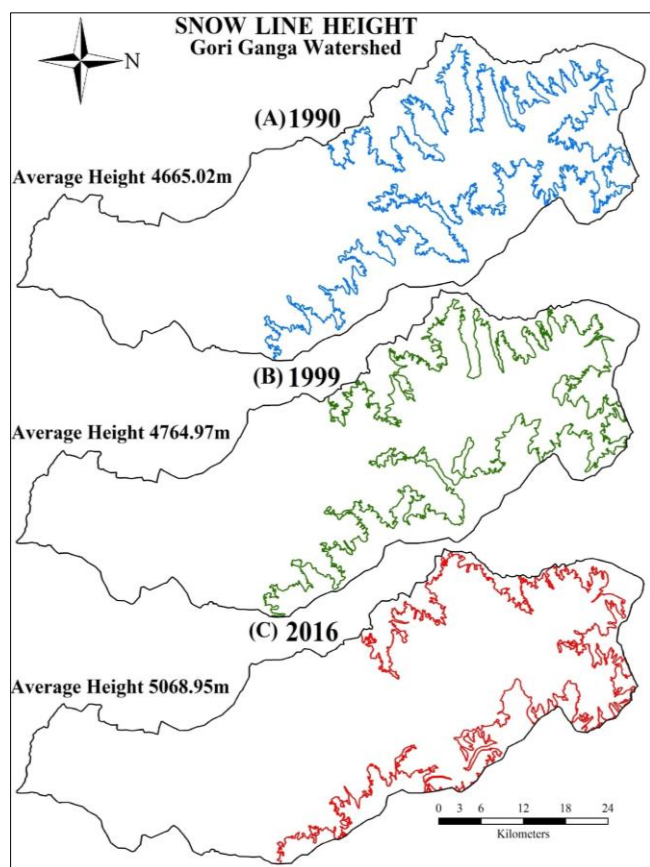
Figure 7 (A) depicts the spatial distribution of snow line of the Gori Ganga watershed in 1990 which reveals that the average height of snow line in the study area was  $4665.02\text{m} \pm \text{Sd } 407.20\text{m}$  (Table 1).

### Snow Line in 1999

Figure 7 (B) depicts the spatial distribution of the snow line of the Gori Ganga Watershed for the year 1999. It reveals that the average height of snow line in the Gori Ganga Watershed was  $4764.97\text{m} \pm \text{Sd } 438.61\text{m}$  (Table 1).

### Snow Line in 2016

Figure 7 (C) depicts the spatial distribution of the snow line of the Gori Ganga Watershed for the year 2016. The map reveals that the average height of snow line in the Gori Ganga Watershed was 5068.95m ± Sd 398.74m (Table 1).



**Fig 7:** Snow line height in different years in the Gori Ganga watershed (A) 1990, (B) 1999 and (C) 2016 (based on Landsat satellite imageries and Cartosat-1 data).

### Nature of Changes in Snow Line

In this section the nature and location of snow line on the Gori Ganga watershed is define in terms of snow line changes pattern, snow line retreat rate and snow line changes trend.

### Snow Line Changes Pattern

Using the data of snow line average height in the study area on different years as depicted in figure 7 the amount of shifts of snow line from 1990-1999 and 1999-2016 was worked out. The results are presented in Table 2 which is reveals that the snow line was shifted about 99.95m upward during 1990-1999 and about 303.98m upward during 1999-2016. Based on these data last two decades 1990 to 2016 (26 years) the snow line at the Gori Ganga watershed was shifted about 403.93m (Figure 8) upward due to global warming and climate change.

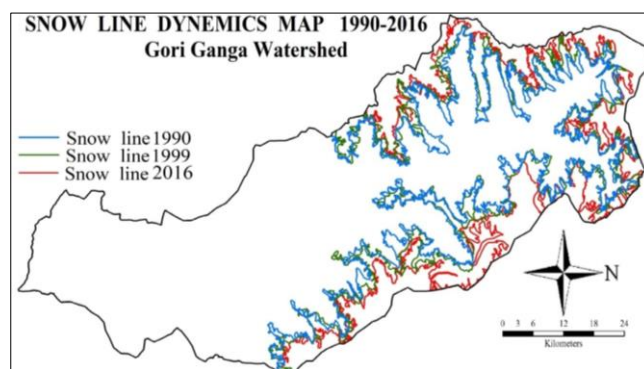
### Snow Line Retreat Rate and Trend

Based on Figure 8 snow lines shift during different periods i.e. 1990, 1999 and 2016, amount of shifting snow line was worked out and results are presented on Table 2. Table 2 reveals that during 9 years (from 1990-1999) the snow line of the Gori Ganga

watershed was shifted upward at the rate of 11.1m/year. During 17 years (from 1999-2016) the rate of snow line shifting 17.88m/year of the watershed was changed from snow cover area to non-snow cover area. Based on these data the snow line in the Gori Ganga watershed was shifted at an average rate of 15.53m/year during the last 26 years (from 1990-2016) presented on Figure 8. The pattern of 26 years snow cover studies in three different time period in 1990, 1999 and 2016 reveals that there is strong negative trend of snow cover with global warming. Which means as the temperature is rising due to global warming the snow cover area is decreasing.

**Table 2:** Amount and rate of snow line shift in different periods in the Gori Ganga watershed.

years	Period	Changes on snow line	
		Amount	Rate
1990-1999	9	99.95m	11.1m/year
1999-2016	17	303.98m	17.88m/year
1990-2016	26	403.93m	15.53m/year



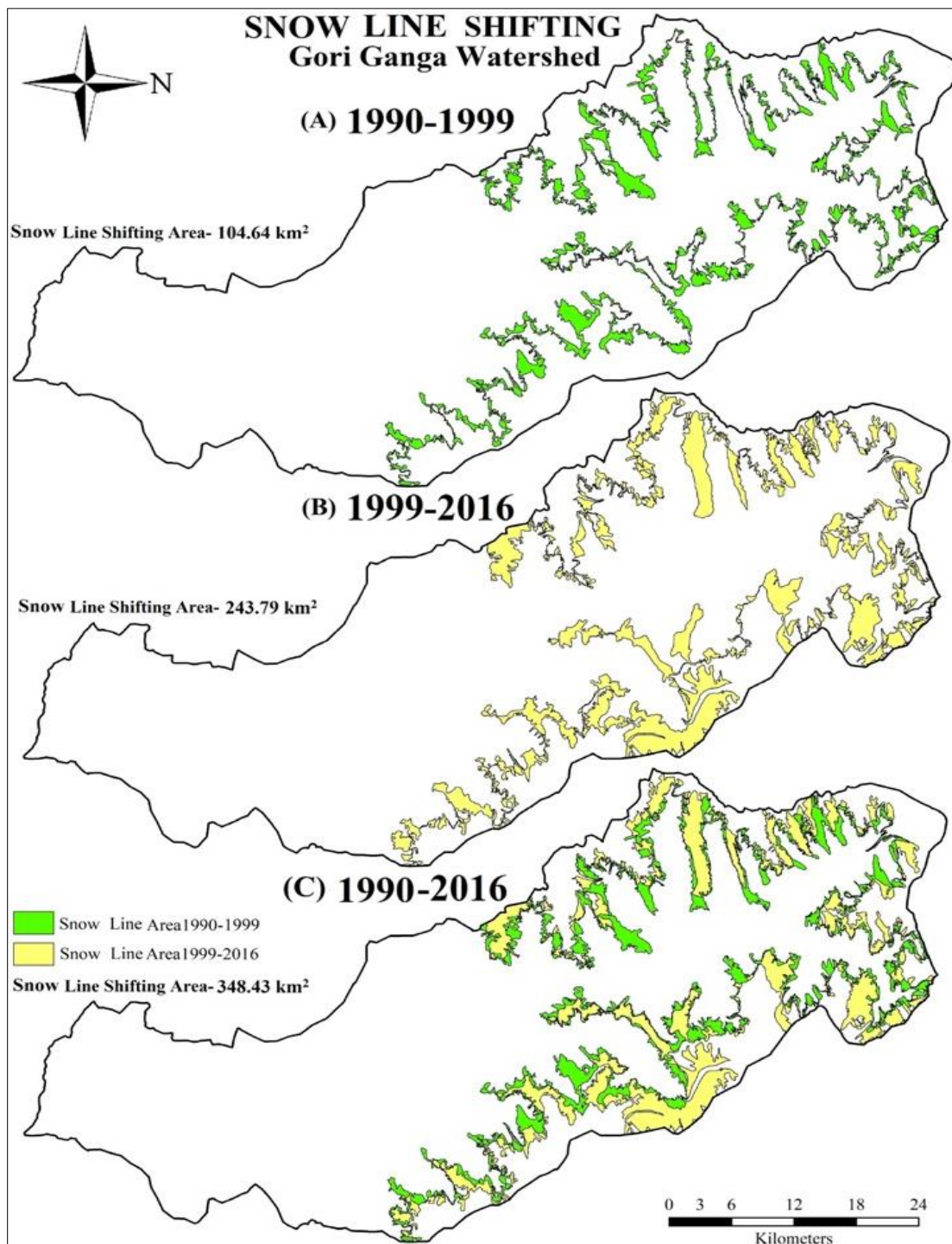
**Fig 8:** Snow line dynamic in the Gori Ganga Watershed since 1990 to 2016 (based on Landsat Satellite Imageries and Cartosat-1 data).

### Snow Line Shifting

The data presented in Table 3 suggest that due to global warming the snow line average height in the Gori Ganga watershed has been shifted towards higher elevation and has been depleted considerably during the last two decades. Result reveal that during 1990 to 2016, about 348.43 km<sup>2</sup> snow cover of the Gori Ganga watershed has been converted into non-snow cover area from the snow cover area at an average rate of 13.40 km<sup>2</sup>/year (Table 3). The change from snow cover area to non-snow cover area during 1990 to 1999 was found about 104.64 km<sup>2</sup> at the rate of 11.63 km<sup>2</sup>/year and 1999 to 2016 was found about 243.79 km<sup>2</sup> at the rate of 14.34 km<sup>2</sup>/year respectively Table 3.

**Table 3:** Amount and rate of snow line shifting area during different period in the Gori Ganga watershed, Kumaun Himalaya, Uttarakhand (India)

Year	Period	Shifting of snow line shifting area	
		Area	Shifting Rate
1990-1999	9	104.64 km <sup>2</sup>	11.63 km <sup>2</sup> /year
1999-2016	17	243.79 km <sup>2</sup>	14.34 km <sup>2</sup> /year
1990-2016	26	348.43 km <sup>2</sup>	13.40 km <sup>2</sup> /year



**Fig 9:** Distribution of snow line shifting area based on NDSI values (>0.4) in different years in the Gori Ganga watershed (A) 1990, (B) 1999 and (C) 1990-2016 (based on Landsat-8, satellite imageries).

### Conclusion

The fundamental objective of the present study is to snow line dynamics in the Gori Ganga watershed, which also includes the study of their patterns, rate and trends using remote sensing and GIS techniques. Based on previous study the following can be concluded.

1. The snow line is the study area 99.95m upward during 1990-1999 and about 303.98m above during 1999-2016. On an average the last two decades (1990 to 2016) the snow line in

the Gori Ganga watershed has been shifted 403.93m upward due to global warming and climate change.

2. These data reveals that the snow line of the Gori Ganga watershed has been shifted upward at the rate of 11.1m/year during 1990-1999 and the rate of 17.88m/year during 1999-2016. On an average rate 15.53m/year during 1990-2016.
3. Present study is based on remote sensing data, i.e. Landsat TM and Cartosat-1 using GIS techniques and has demonstrates that the remote sensing and GIS techniques are

very useful for the study of determination and dynamics of snow line.

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