



RESEARCH ARTICLE

SPATIO-TEMPORAL CHANGE IN SNOW COVER AREA USING RS & GIS IN THE GORI GANGA WATERSHED, KUMAUN HIGHER HIMALAYA

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Abstract

Present research paper is an attempt to examine the dynamics of snow cover by using Normalized Difference Snow Index (NDSI) in Gori Ganga watershed, Kumaun Himalaya, Uttarakhand (India). For the study of snow cover of Landsat satellite imageries of three different time periods like Landsat TM of 1990, Landsat TM of 1999 and Landsat TM 2016 were used. Geographical distribution of snow cover reveals that in 1990 about 30.97% (678.87 km²), in 1999 about 25.77% (564.92 km²) area of the Gori Ganga watershed was under snow cover while in 2016 the snow cover was found only 15.08% (330.44 km²). These data suggest that due to global warming about 348.43 km² snow cover of Gori Ganga watershed has been converted into non-snow cover area at an average rate 13.40 km²/year during the last 26 years.

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Introduction:-

Snow is a key component for energy balance of the earth's i.e. environment, climate and a major source of fresh water in many Himalayan regions. The Himalayan glaciers and region home of permanent snowfields, which from the largest bodies of ice outside of polar ice caps (Raina and Srivastava, 2008). As a important regional water resource, the Himalayan snow caps and winter seasonal snow melts make an major contribution to the drinking water, agriculture, and hydropower supply for a populated region in downstream river basins (Immerzeel et al. 2010). Satellite-based remote sensing is a convenient tool for the study of cryosphere that allows to carry out investigations over large inaccessible areas and analysis has been done using moderate-resolution imaging spectroradiometer (MODIS) satellite data for the past 11 years (2000-2010) with the temporal snow cover being derived using the Normalized Difference Snow Index (Joshi et al. 2015).

In the recent past, satellite-based remote sensing techniques have been widely used globally for investigating glacier fluctuations and snow cover changes (Kulkarni and Rathore, 2003). Due to accessibility and difficult terrain, only limited numbers of glaciers are monitored continuously in Indian Himalaya after 2000 to 2017. The Gangotri glacier, Dokriani glacier, Pindari glacier, Milam glacier, Chorbari glacier, Satopant glacier, Bhagirathi Kharak glacier, Parbati glacier, Samudra Tapu Glacier, Chhota Shigri glacier and Kolahoi Glacier are the most studied glaciers with field and satellite data (Naithani et al. 2001; Kulkarni et al. 2005; Dobhal et al. 2008, Dobhal et al. 2004; Raj 2011; Bhambri et al. 2012; Bali et al. 2013; Raj et al. 2014; Mehta et al. 2014; Rashid et al. 2017). Table 1 present a compilation of recession of some selected glaciers in the Indian Himalaya.

The fundamental objective of the present paper is to study the snow cover dynamic of a Higher Himalayan watershed viz. the Gori Ganga.

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Table 1:- Recession of Himalayan glaciers through last century.

Glacier	Period	Years	Recession (M)	Average Rate (M/Yr)	References
Pindari Glacier	1966-2010	44	379	8.6	Bali et al. 2013
Parbat Glacier	1962-2001	39	6569	168	Kulkarni et al. 2005
Chorabari Glacier	1962-2012	50	344	6.8	Mehta et al. 2014
Gangotri Glacier	1962-1999	37	1250	34	Naithani et al. 2001
	1965-2006	41	819	19	Bhambri et al. 2012
Milam Glacier	1954-2006	52	1328	25.5	Raj 2011
Dokriani Glacier	1962-2000	38	641.5	16.88	Dobhal et al. 2008
Kolhoi Glacier	1857-2014	157	2850	18.2	Rashid et al. 2017
Tiprabank Glacier	1960-1986	26	325	12.5	Dobhal et al. 2004
South Lhonak	1962-2008	46	1900	41	Raj et al. 2014

Study Area

The study area, viz., the Gori Ganga Watershed (Kumaun Himalaya) extends between $29^{\circ}45'0''\text{N}$ to $30^{\circ}35'47''\text{N}$ latitudes and $79^{\circ}59'33''\text{E}$ to $80^{\circ}29'25''\text{E}$ longitude, and encompasses an area of 2191.93 km^2 (Figure 1). The altitude of the Gori Ganga watershed varies in 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, in three Tehsils, i.e., Munsyari, Dharchula and Didihat. Munsyari remains one of the last accessible hill stations by motor road in the region. The Munsyari and Madkote towns located in the study area are currently the starting point for many track routes into the Himalayan interior.

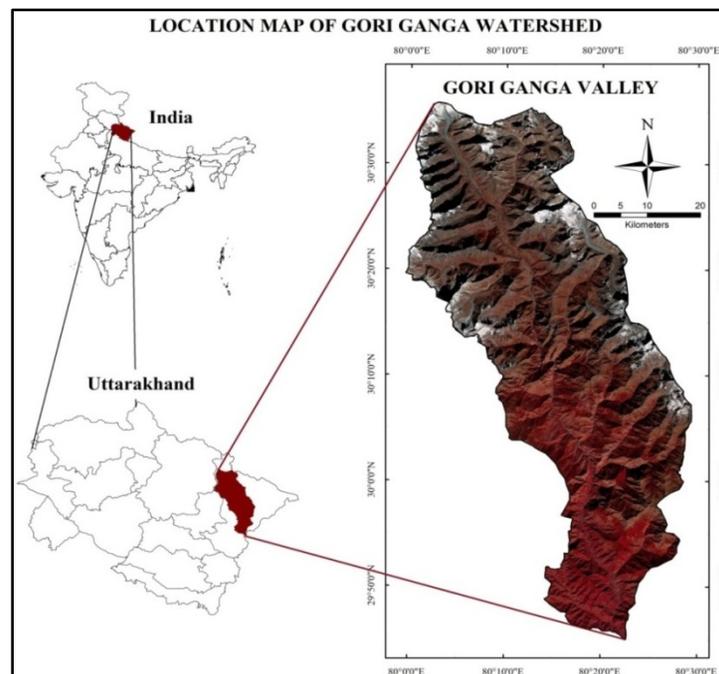


Figure 1:- Location map of the study area Viz., Gori Ganga watershed, Kumaun Higher Himalaya.

Methodology:-

To examine the snow cover area 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 image is of Landsat TM of 15 November 1999 at 30 m resolution and the third image used for the present study is Landsat TM of 28 November 2016 at 30 m resolution. These imageries helped in understanding extend of snow cover area in the watershed over the last 26 years (i.e. 1990 to 2016). Figure 2 is presenting a flowchart of the methodology adopted. Additionally, the reflectance of clouds remains high in the SWIR band, thus NDSI allows discriminating some clouds and snow. NDSI is useful for the 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). NDSI is defined by the following relation and it ranges from -1 to +1 (Kulkarni et al., 2003). To handle the mixed area, the threshold value of NDSI was lowered from 0.4 to 0.1 (Klein et al. 1998).

Result And Discussion:-

The results obtained through the analysis of NDSI imagery are diagrammatically illustrated in Figure 3 and 4 and are registered in Table 2 and 3. Figure 3 depicts distribution of NDSI variation while Figure 4 depicts geographical distribution of snow cover area in 1990, 1999 and 2016 in the study area. Figure 5 depicts dynamics of snow cover area in 1990 to 2016. A brief account of these results it's discussed in the following paragraphs.

Normalized Difference Snow Index (NDSI)

NDSI is useful for the 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). NDSI uses the high and low reflection of snow in visible (green) and shortwave infrared (SWIR) regions respectively and it can also delineate and map the snow in mountain shadows. Additionally, the reflectance of clouds remains high in the SWIR band. Thus NDSI allows discriminating clouds and snow. NDSI is defined by the following relation and it ranges from -1 to +1 (Kulkarni et al., 2002).

$$NDVI = \frac{\text{Green} - \text{SWIR}}{\text{Green} + \text{SWIR}}$$

In the methodology described for NDSI using Landsat data. Using ArcGIS software, three different years (1990, 1999, and 2016) Landsat data were taken for calculating the NDSI index for Gori Ganga watershed. A 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). Figure 3 is the normalized difference snow index which is based on Landsat-8 satellite imageries of three different time periods, i.e., Landsat TM of 1990, 1999 and 2016.

Status of Snow Cover

From the Figure 4 which is based on NDSI values of Figure 3, area under snow cover for different years was worked out which is presented in Table 2. Table 2 reveals that the snow cover area in Gori Ganga watershed was about 30.97% (678.87 km²) in 1990, 25.77% (564.92 km²) in 1999 and 15.08% (330.44 km²) in 2016.

Table 2:- Snow cover area and their percentage in different years in the Gori Ganga watershed (based on Landsat-8 Satellite imageries).

Years	Area in km ²	Percentage	Total Area km ²
1990	678.87	30.97	2191.93
1999	564.92	25.77	2191.93
2016	330.44	15.08	2191.93

Shifting in Snow Cover

The data presented in Table 3 suggest that due to global warming the snow cover area in the Gori Ganga watershed has been shifted towards higher elevation and has been depleted considerably during the last two and half decades. Result reveal that during 1990 to 2016, about 348.43 km² 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 km²/year (Table 3). The change from snow cover area to non-snow cover area during 1990 to 1999 was found about 104.64 km² at the rate of 11.63 km²/year and 1999 to 2016 was found about 243.79 km² at the rate of 14.34 km²/year, respectively (Table 3).

Table 3:- Amount and rate of snow cover change during different period in the Gori Ganga watershed, Kumaun Himalaya, Uttarakhand (India).

Year	Period	Shifting of Snow Cover	
		Area	Shifting Rate
1990-1999	9	104.64 km ²	11.63 km ² /year
1999-2016	17	243.79 km ²	14.34 km ² /year
1990-2016	26	348.43 km ²	km ² /year 1.40

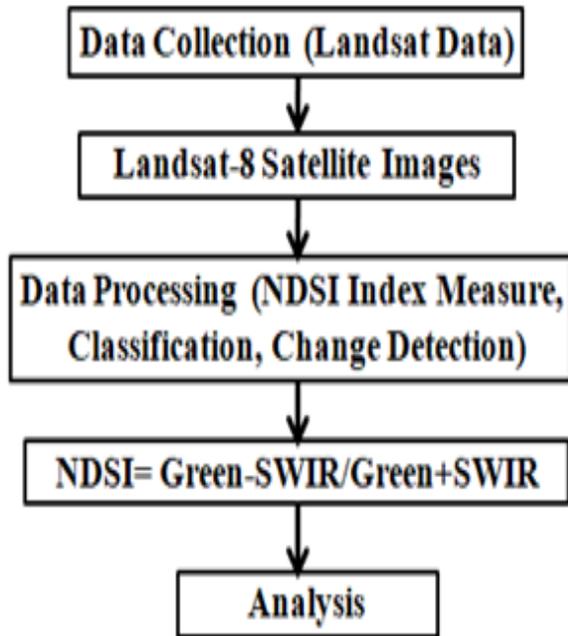


Figure 2: Flowchart of methodology

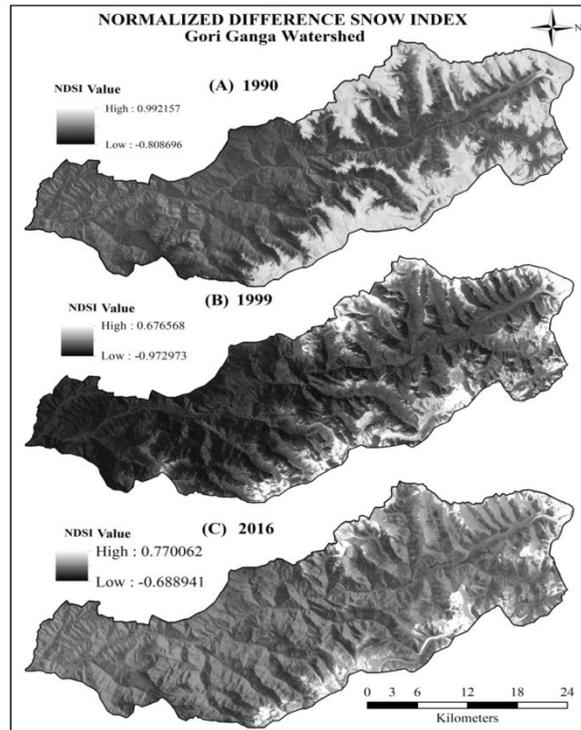


Figure 3: Normalized Difference Snow Index (NDSI) map values (>0.4) in different years in the Gori Ganga watershed, (A) 1990, (B) 1999 and (C) 2016 (based on Landsat-8 Satellite imageries).

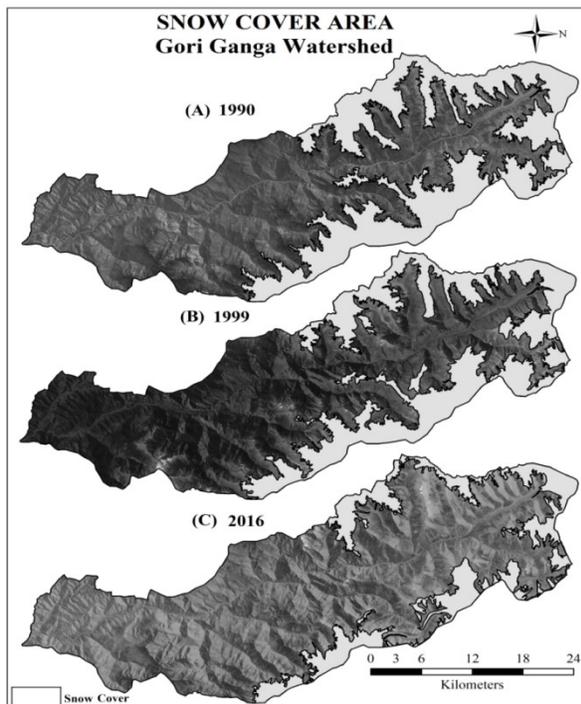


Figure 4: Geographical distribution of snow cover area based on NDSI Values (>0.4) in different years in the gori ganga watershed, (A) 1990, (B) 1999 and (C) 2016 (based on Landsat-8, Satellite imageries).

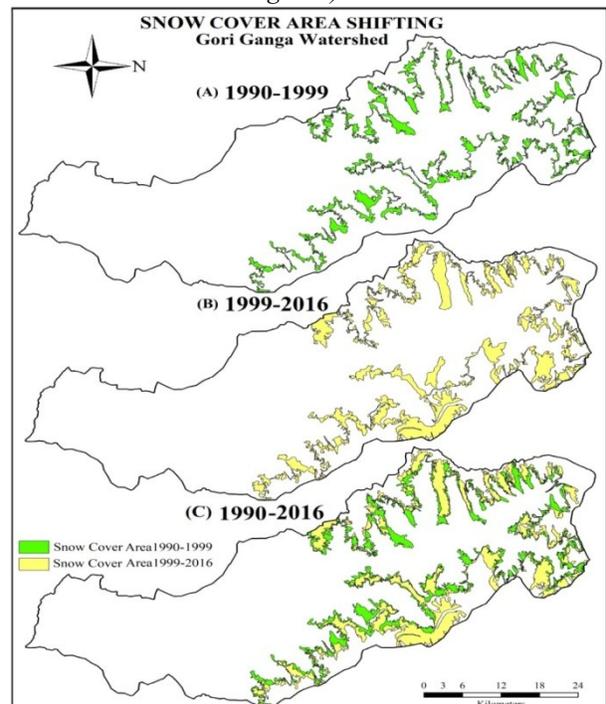


Figure 5: Dynamic distribution of snow cover area based on NDSI values (>0.4) in different years in the Gori Ganga watershed, (A) 1990, (B) 1999 and (C) 2016 (based on Landsat-8, Satellite imageries).

Conclusion:-

The present study was carried out in a Kumaun Himalayan watershed, viz., Gori Ganga watershed. The study reveals that from 1990 to 2016 about 348.43 km² area of the watershed has been converted into non-snow cover area from snow cover area. With the help of these data, it can be extrapolated that the snow cover area in Gori Ganga watershed is depleting at the average rate of 13.40 km² per year. It is evident from present study that the snow cover area is decline confirmed steadily in the Kumaun Himalaya due to global warming. If the trends of snow cover depletion, the water resource of the region will be in danger which may result in severe environmental degradation, social disruption and ecological damages in the Kumaun Himalayan region. This study has well demonstrated the applications of geospatial technology in studying snow dynamics.

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