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AN ASSESSMENT OF CHANGES IN EXTENT OF GLACIERS IN KUMAUN HIMALAYAS

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Keyword

Glacier Extent, Change detection, Remote Sensing, Landsat Series, DEM, Visual Interpretation.

Abstract

Recent decades have witnessed significant impacts from climate change. Due to climate change glacier are retreating, shrinking, and disappearing worldwide. Studying glaciers from a wide range of remote sensing platforms and techniques has become an expanding field over the past decade. This study presents an assessment of changes in extent of glaciers in kumaun Himalayas. In this study, Remote sensed satellite based datasets have been used for extent of glacier. Landsat 5 TM, landsat 7 ETM+ and landsat 8 OLI/TIRS were taken and studies for three time periods, 1997, 2008 and 2017. The visual interpretation methods were applied to identify the glacier & their extent using multi-temporal data. Cartosat version -3 DEM was used to identify the topography of the study area. The result depicts that Glacier area in the current study of the kumaun Himalaya for the year 1997, 2008, and 2017 are **435.15**km^2, **290.7**km^2, and **239.85**km^2.The glaciers over the years are showing a decline in their area. In this study a challenge has been made to quantitatively define the glacier extent and their rate of decrease.

Introduction

The Himalaya comprises one of the largest collections of glaciers outside the Polar Regions, with a total glacier cover of 33,000km2 and around 9600 glaciers exist in the Indian Himalaya (1). These glaciers are source of water for major rivers systems of Asia (Indus, Ganga and Brahmaputra). The water discharge from Himalayan glaciers along with precipitation (seasonal and monsoon) contributes to the overall run-off of Himalayan rivers (2). Nowadays, there is lot of concern about the fluctuations of glaciers due to global warming and climate change. The glaciers are sensitive to climate and are well recognized as the most reliable indicators of climate change (IPCC 2007). The Himalayan glaciers are also affected with the process of climate change and various studies suggest that many of them have receded in recent decades due to global warming (4). To analyze the impact of global warming on glaciers, monitoring the fluctuations of glaciers over time is needed, which is a time taking and resource intensive process (5). Hence to overcome this challenge, Remote sensing techniques are often the only way to analyze glaciers in remote mountains and to monitor a large number of glaciers at the same time (6). This study focused on Kumaun Himalayan glaciers for the period of 1997, 2008 and 2017. The Quantitative and qualitative of the glacier extent have been analyzed with the help of satellite data.

Objectives

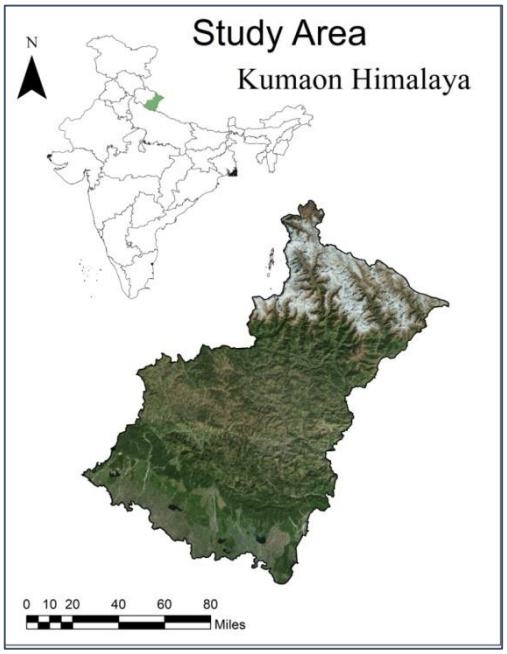
Multi-temporal datasets have been used to perform the study for extent of changes and retreat in glacier cover area in the Kumaun Himalaya.

The objectives of the study can be summarized as:

- To extract the extent of glacier area from the satellite images using Landsat satellite data.
- Statistically change detection in area of glacier of Kumaun Himalaya in the time frame (1997, 2008 and 2017).

Study Area

Kumaun Himalaya is situated in the state of Uttrakhand, India (latitude $28^0$44/ N to $30^0$49/ N and longitude $78^0$45/ E to $81^0$5/ E (Sharma, 2012). In the east stream Kali makes its global limit with Nepal. In the north the Great Himalaya makes another universal limit with China. The Uttar Pradesh is situated in the south and Himachal Pradesh is arranged in the south bearing. Kumaun Himalaya is spread more than six regions.



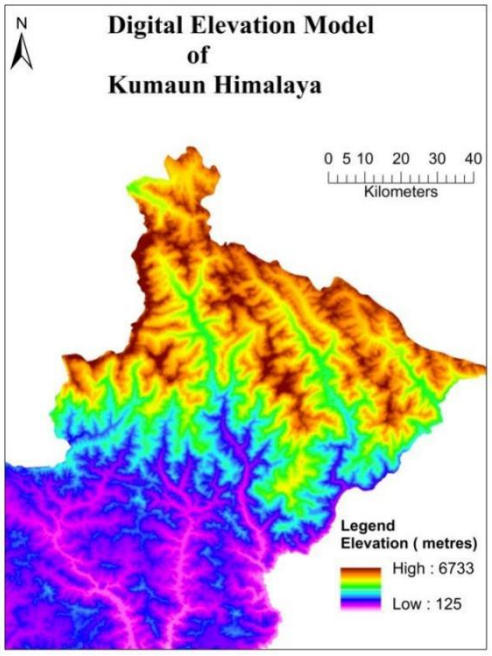


Figure1: Study Area of Kumaun Himalaya, Figure 2: Digital elevation Model of Kumaun Himalaya.

The monthly temperature varied between 1.5ºC (January) and 23.9ºC (May) and monthly mean total rainfall ranged between 6.3 mm (November) and 310.6 (July) based upon the meteorological data recorded at Mukteswar (2286m amsl) by Indian Meteorological Department.

Data used

The data used in this study have been downloaded from the various sources. Data used in this study are following:

- Landsat 5 TM, Landsat ETM+ and Landsat 8 OLI/TRIS.
- Cartosat version 3, DEM (Digital Elevation Model) obtain from TERI IHC.
- GLIMS data downloaded from Randolph Glacier Inventory

Table 1: The following table shows the information of datasets.

Satellite Sensors	Date	Month	Year	Spatial resolution
Landsat 5 TM	2	November	1997	30
Landsat 7 ETM+	8	November	2008	30
Landsat 8 OLI , TIRS	25	November	2017	30

Methodology

The methodology involves the change detection task of glacier extent using Landsat satellite imagery across multiple acquisition times. We address glacier in terms of analyzing the extent of glaciers over the different time periods. This study firstly identified the glaciers based on visual interpretation technique method using Landsat 5, 7 and 8 for the year 1997, 2008 and 2017. Google earth pro have been used for the visualization of glacier, this one is an alternate way of identification of glacier extent in a real time. The DEM have been used to generate the topography of study area, which helps in to demarcate the boundary of glacier extent. The validations of glacier extent boundary were verified from the GLIMS datasets (7).

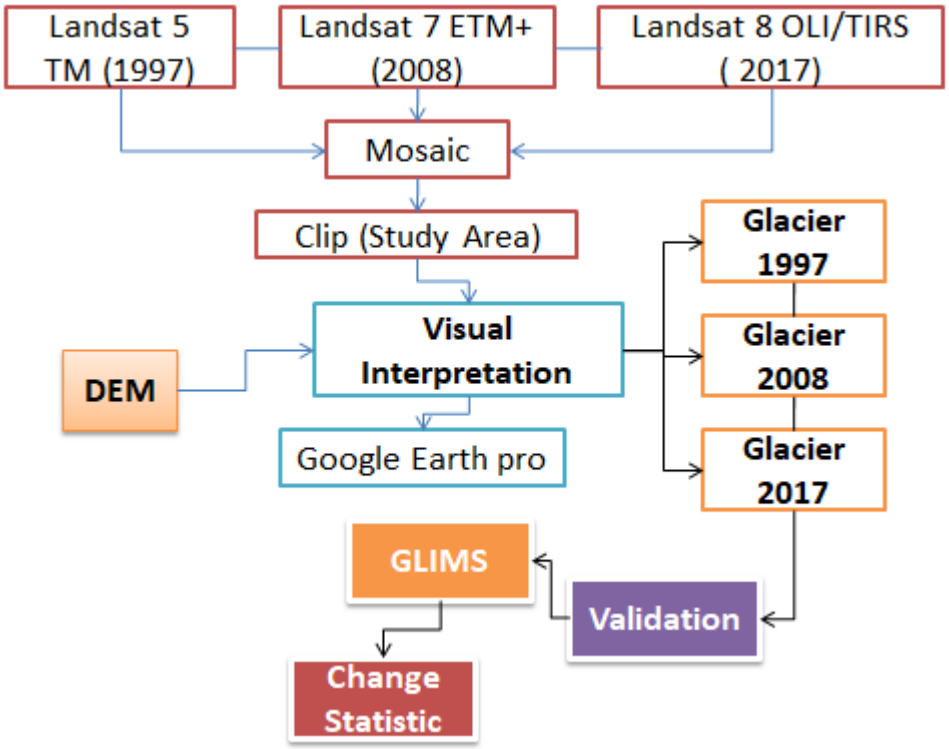


Figure 3: Flow chart of methodology

Digital Elevation Model– In this study, Cartosat version-3 DEM have been used for generate the topography of study area. DEM provides the elevation details, which helps into the identification of glacier edges.

Results and Discussion

Extent of Glacier Area

The present study, delineate the 40 glaciers, in each decadal time period (1997, 2008 and 2017) using Landsat series. GIS tool will apply to calculate the glacier area for each glacier in different time period. The total area of glacier is 435.15km2 for the year 1997; the total area glacier for the year of 2008 is 290.7 km2 and the total area of glacier in 2017 is 239.85km2. In this study, the quantitative analysis have been applied on glacier extent for the year of 1997, 2008 and 2017, the results depicts the 40 glaciers are continue decline in area for each decadal year. The total areas of each 40 glaciers have been showing in table no.2 and figure 4. Showing the extent of glacier.

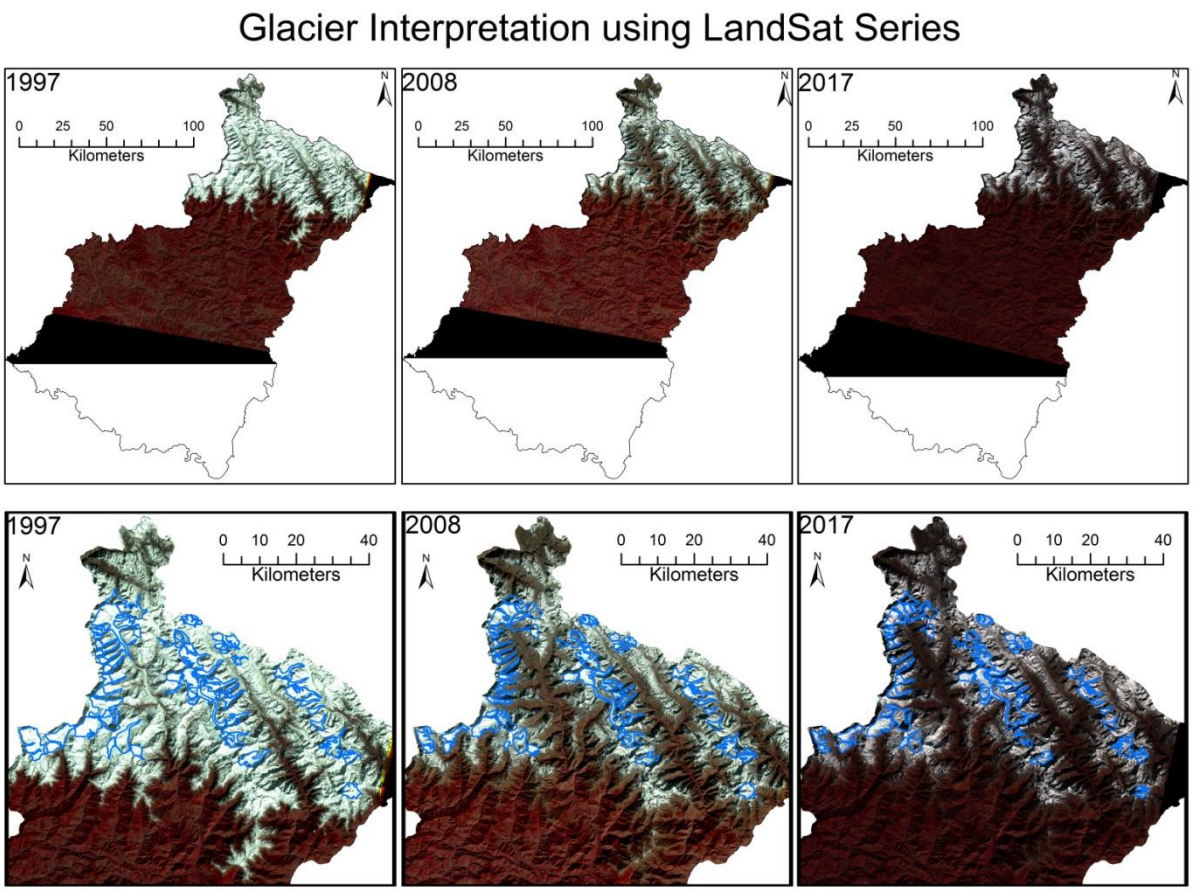


Figure 4: Glacier Interpretation using Landsat series.

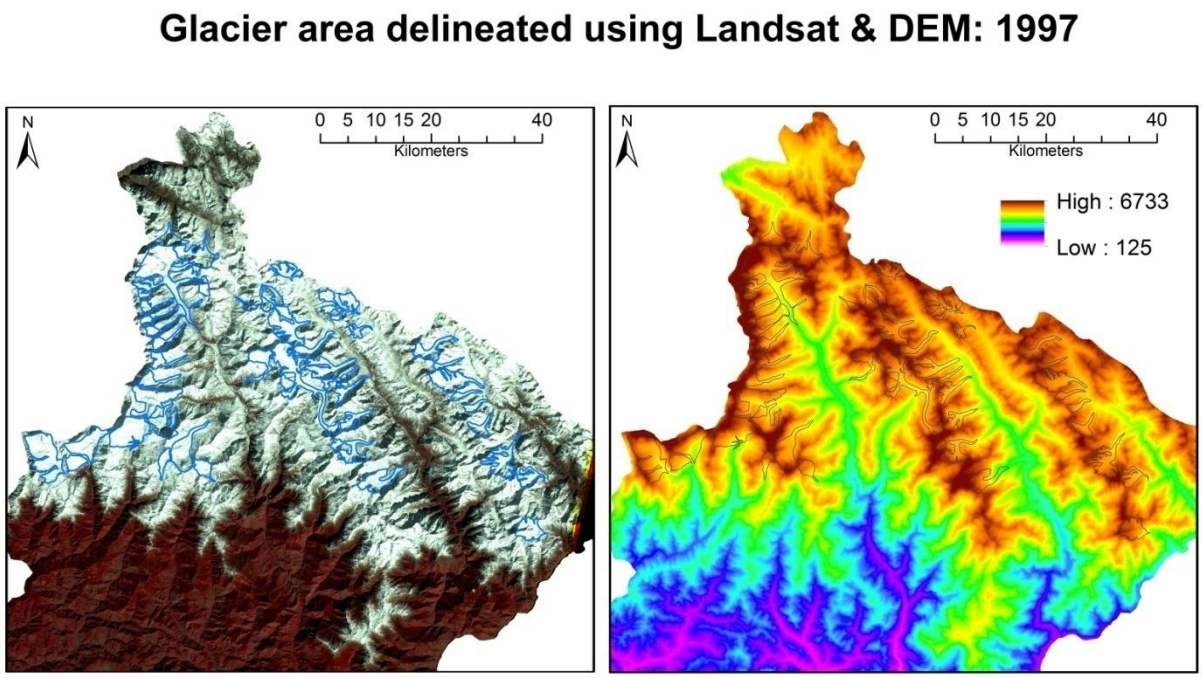


Figure 5: Digitized Glacier Area of 1997 to overlap DEM.

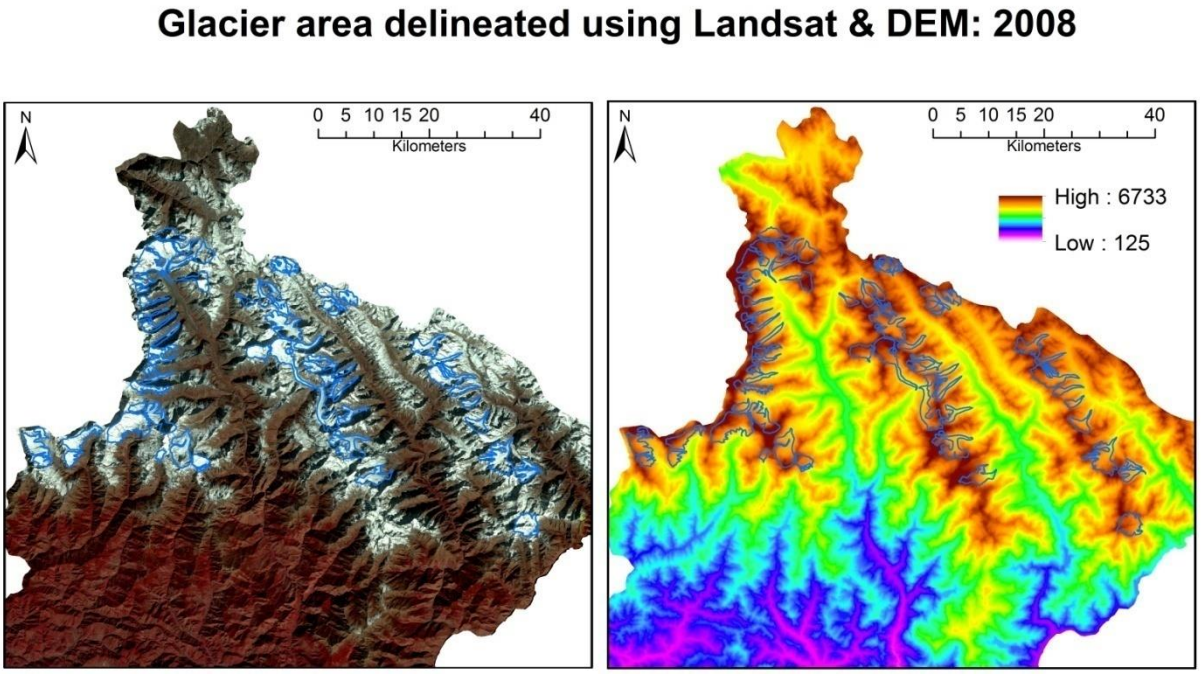


Figure 6: Digitized Glacier Area of 2008 to overlap DEM

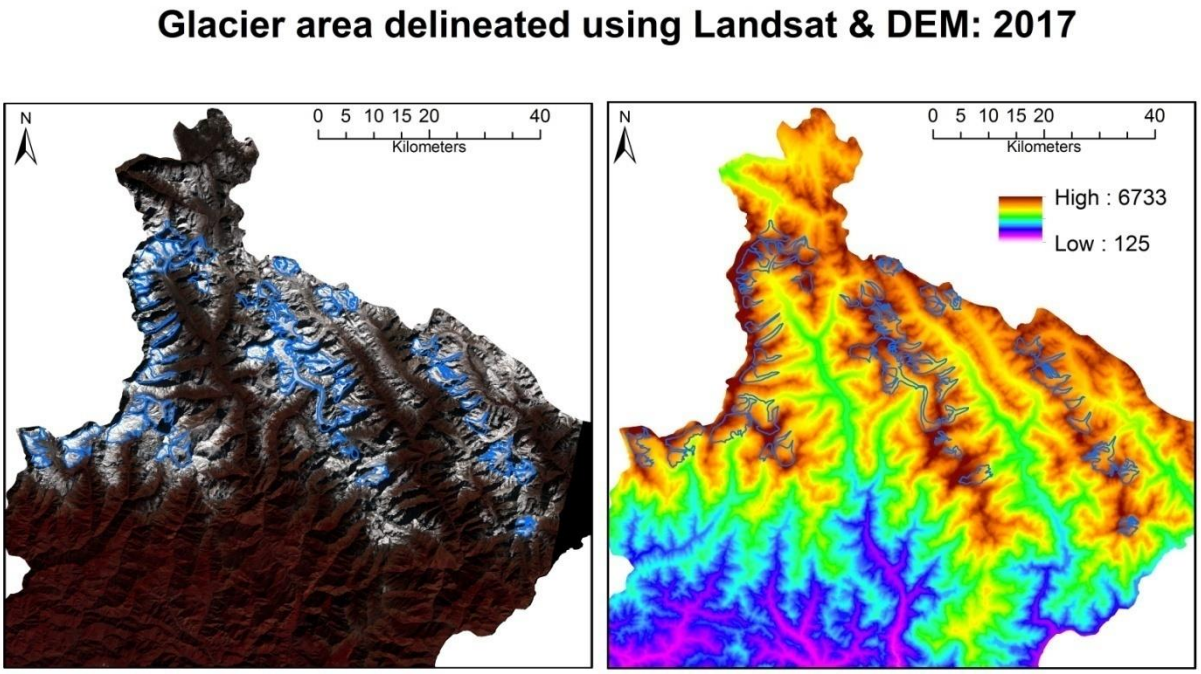


Figure 7: Digitized Glacier Area of 2017 to overlap DEM

	Area (Km^2)			Decade wise Percent Area Change			
S. No	**1997**	**2008**	**2017**	**S. No**	**1997-2008**	**2008-17**	**1997-2017**
Glacier : 1	6.07	2.58	2.3	Glacier : 1	-57.5	-10.85	-62.11
Glacier : 2	10.43	6.36	5.49	Glacier : 2	-39.02	-13.68	-47.36
Glacier : 3	7.06	3.65	2.85	Glacier : 3	-48.3	-21.92	-59.63
Glacier : 4	61.64	38.18	32.52	Glacier : 4	-38.06	-14.82	-47.24
Glacier : 5	9.65	8.25	7.86	Glacier : 5	-14.51	-4.73	-18.55

Glacier : 6	10.82	5.97	4.35	Glacier : 6	-44.82	-27.14	-59.8
Glacier : 7	43.77	27.45	26.15	Glacier : 7	-37.29	-4.74	-40.26
Glacier : 8	13.97	12.37	7.95	Glacier : 8	-11.45	-35.73	-43.09
Glacier : 9	12.89	11.65	9.47	Glacier : 9	-9.62	-18.71	-26.53
Glacier : 10	6.99	3.99	3.04	Glacier : 10	-42.92	-23.81	-56.51
Glacier : 11	10.09	8.8	7.49	Glacier : 11	-12.78	-14.89	-25.77
Glacier : 12	11.14	9.13	8.72	Glacier : 12	-18.04	-4.49	-21.72
Glacier : 13	3.18	3.02	2.49	Glacier : 13	-5.03	-17.55	-21.7
Glacier : 14	17.13	10.58	6.58	Glacier : 14	-38.24	-37.81	-61.59
Glacier : 15	4.55	3.66	3.46	Glacier : 15	-19.56	-5.46	-23.96
Glacier : 16	13.16	10.36	9.66	Glacier : 16	-21.28	-6.76	-26.6
Glacier : 17	9.13	7.09	5.09	Glacier : 17	-22.34	-28.21	-44.25
Glacier : 18	13.76	8.12	7.66	Glacier : 18	-40.99	-5.67	-44.33
Glacier : 19	2.28	1.93	1.75	Glacier : 19	-15.35	-9.33	-23.25
Glacier : 20	3.57	2.69	2.42	Glacier : 20	-24.65	-10.04	-32.21
Glacier : 21	8.5	5.27	4.98	Glacier : 21	-38	-5.5	-41.41
Glacier : 22	8.66	6.69	5.9	Glacier : 22	-22.75	-11.81	-31.87
Glacier : 23	8.71	5.73	4.92	Glacier : 23	-34.21	-14.14	-43.51
Glacier : 24	6.02	4.07	2.2	Glacier : 24	-32.39	-45.95	-63.46
Glacier : 25	14.12	12.73	9.99	Glacier : 25	-9.84	-21.52	-29.25
Glacier : 26	24.11	8.39	6.37	Glacier : 26	-65.2	-24.08	-73.58
Glacier : 27	3.15	2.83	1.7	Glacier : 27	-10.16	-39.93	-46.03
Glacier : 28	3.76	2.41	2.02	Glacier : 28	-35.9	-16.18	-46.28
Glacier : 29	7.68	5.18	4.12	Glacier : 29	-32.55	-20.46	-46.35
Glacier : 30	5.98	2.01	1.72	Glacier : 30	-66.39	-14.43	-71.24
Glacier : 31	15.75	8.34	7.57	Glacier : 31	-47.05	-9.23	-51.94
Glacier : 32	15.18	10.46	9.24	Glacier : 32	-31.09	-11.66	-39.13
Glacier : 33	4.22	3.69	2.73	Glacier : 33	-12.56	-26.02	-35.31
Glacier : 34	4.76	3.71	3.15	Glacier : 34	-22.06	-15.09	-33.82
Glacier : 35	2.98	2.87	2.33	Glacier : 35	-3.69	-18.82	-21.81
Glacier : 36	10.45	6.82	5.27	Glacier : 36	-34.74	-22.73	-49.57
Glacier : 37	2.86	2.28	1.84	Glacier : 37	-20.28	-19.3	-35.66
Glacier : 38	6.93	5.16	1.61	Glacier : 38	-25.54	-68.8	-76.77
Glacier : 39	3.41	1.97	1.67	Glacier : 39	-42.23	-15.23	-51.03
Glacier : 40	6.64	4.26	3.22	Glacier : 40	-35.84	-24.41	-51.51
TOTAL	**435.15**	**290.7**	**239.85**	**TOTAL**	**-33.2**	**-17.49**	**-44.88**

Table 2: Change area matrix and decade wise area of change.

Rate of Decrease in Glacier Extent

Glacier area in the current study of the kumaun Himalaya for the year 1997, 2008, and 2017 are **435.15 km2, 290.7km2, and 239.85km2**. The class of glaciers and rate of Decrease arrange in four categories. The Rate of decrease of glaciers In 1997-2008 less than 20 % glaciers are 12 and between 20 to 40 % glaciers are 19 and 40

to 60 % are 7 and Above 60% are only 2 glaciers. In 2008 to 2017 the rate of decrease of glaciers are Less than 20% is 25, between 20-40% are 13, 40-60 % 1 and Above 60 % is just 1 glaciers lay in this class.

Categorization of retrieving of the Glaciers in Kumaun Himalayas			
Category	**1997-2008**	**2008-17**	**1997-2017**
0-20 %	12	25	1
20-40%	19	13	15
40-60 %	7	1	18
Above 60 %	2	1	6

Table 3: Categorization of retrieving of the Glaciers in Kumaun Himalaya.

The rate of Decrease of glaciers in 1997 to 2017 is another class. Less than 20 % glaciers are 1 and between 20 to 40 % glaciers lay 15, and 40 to 60 % glaciers are lay 18, and above 60 % are 6 glaciers arrange. The following table 3, showing the Statistic of rate of decrease in glacier extent.

Glaciers and Total percentage of their glaciers

The percentage of Total glacier area of Glacier, In 1997 to 2008 less than 20% glacier area is 30 % and 20 to 40 % is 47.5, 40 to 60 % is 17.5 % and above 60% are 5 percent of glacier area of total glacier. In 2008 to 2017 percent of glacier area of total glacier is less than 20% 62.5 and 20 to 40% are 32.5 and 40 to 60 % 2.5 and above 60 % are 2.5 percent of glacier area of total glacier. In 1997 to 2017 percent of glacier area of total glacier is less than 20% are 2.5 % and 20 to 40 % are 37.5 and 40 to 60 % are 45 % and above 60 % are 15 % percent of glacier area of total glacier.

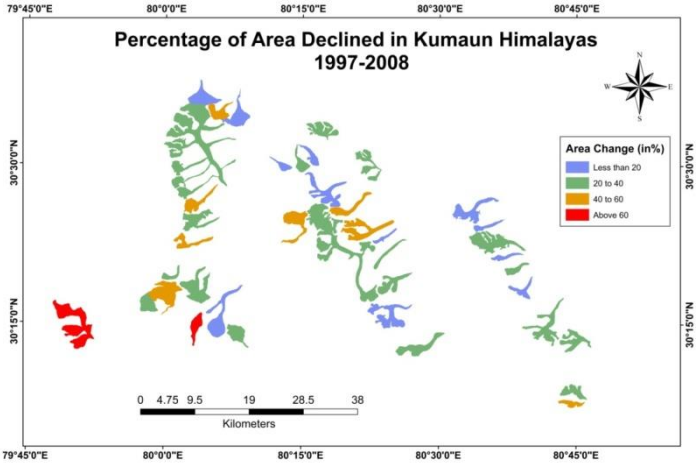


Figure 8: Percentage of area declined in Kumaun Himalayas 1997 to 2008

Categorization of retrieving of the Glaciers in Kumaun Himalayas (in %)			
Category	**1997-2008**	**2008-17**	**1997-2017**
0-20 %	30	62.5	2.5
20-40%	47.5	32.5	37.5
40-60 %	17.5	2.5	45
Above 60 %	5	2.5	15

Table 4: Total Glacier area of total percentage of their glacier.

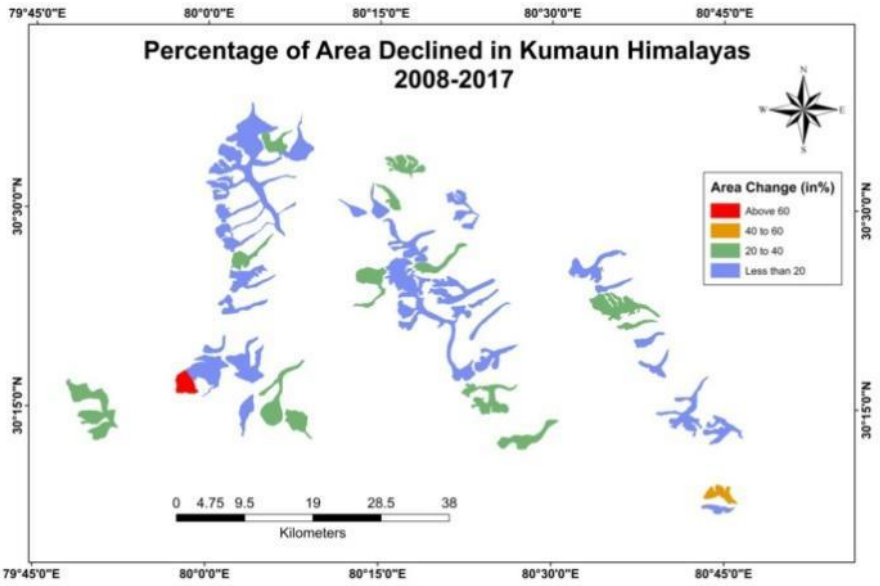


Figure 9: Percentage of area declined in Kumaun Himalayas 2008 to 2017,

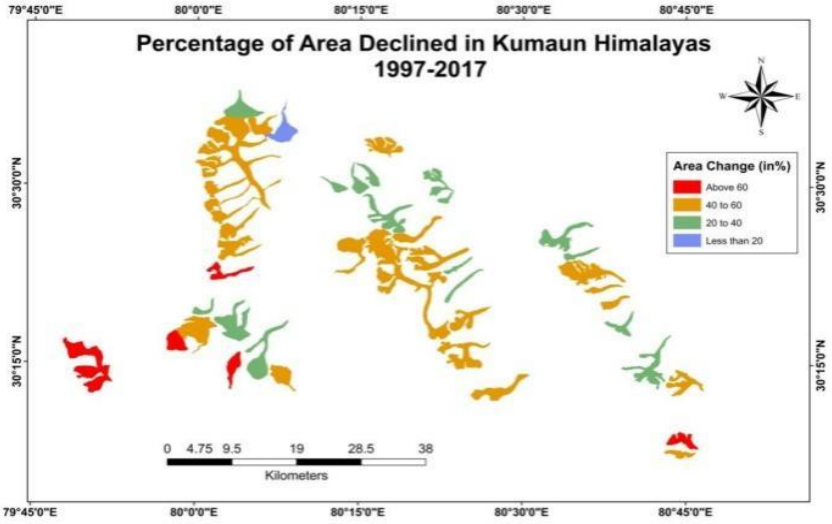


Figure 10: Percentage of area declined in Kumaun Himalayas 1997 to 2017.

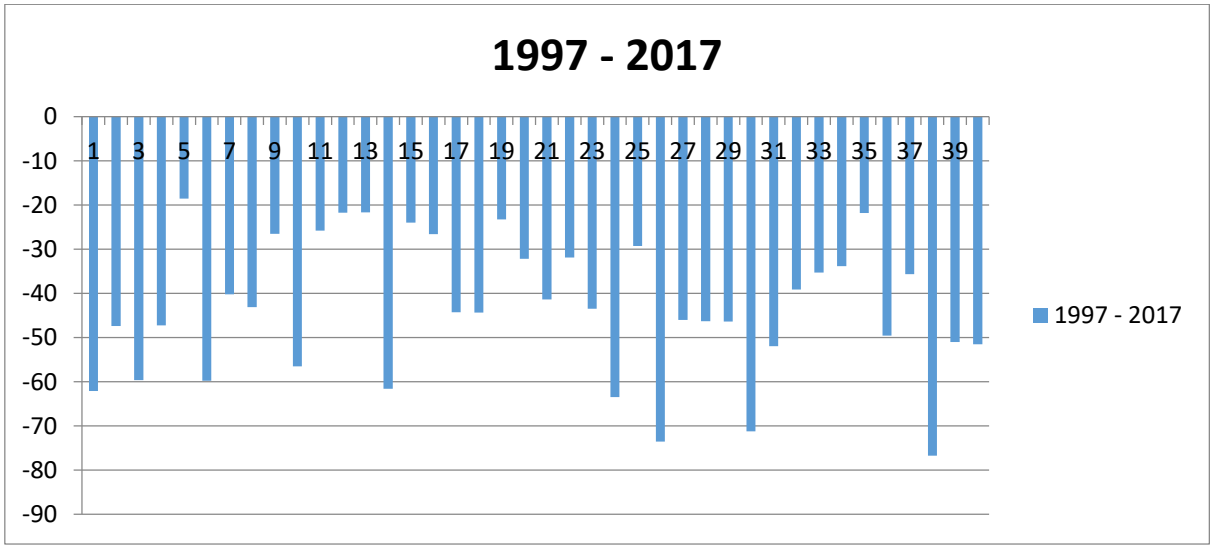


Figure 11: Graphically represent the change of area of glaciers 1997 to 2017.

Conclusion

Multi temporal data has been used in this study to analyze the change detection in glacier extent of Kumaun Himalaya using remote sensing and GIS techniques. The remote sensing and GIS techniques are very useful to monitor the decadal change in the glacier extent and their area of a given region. This study has been undertaken on kumaun Himalaya to access the change in glacier extent in years 1997, 2008, and 2017. Satellite images were taken from LANDSAT TM and ETM+ and Landsat 8 sensors which are freely available in USGS archives. GLIMS data has been used for validation of glacier boundary. The Cartosat version 3 DEM was used to generate the topography of the kumaun Himalaya. In order to extract the glacier extent of kumaun Himalaya was calculated of the study area for the defined years and these were digitized in order to draw polygons of the different glaciers in the kumaun Himalaya for years 1997, 2008, and 2017. The total area came out be **435.15km^2**, **290.7km^2**, and **239.85km^2**The glaciers over the years are showing a decline in their extent. From year 1997 to 2008 and 2008 to 2017 and 1997 to 2017 there has been Rate of Decrease of the glaciers are Category wise divided in four categories. Less than 20 %, 20 to 40 %, 40 to 60 % and Above 60 %. There is also analyze the total no of Glaciers and their total percentage of their glacier is calculated. The extents of the glaciers in this study are showing a continuous decline in area which depicts that the glaciers of the kumaun Himalaya are receding continuously.

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