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Spatio-temporal disposition of Chandra basin Glaciers from 1980 to 2011, Lahaul and Spiti Himalayan Region, Himachal Pradesh, India

Sunil Dhar[1], Arun Kumar[2] and Shashi Kant Rai[2]
[1]Professor, Department of Environment Sciences, Central University Jammu, Rahya Suchani (Bagla) District Samba (Jammu & Kashmir), India.
[2]Research Scholar, Department of Environment Sciences, Central University Jammu, Rahya Suchani (Bagla) District Samba (Jammu & Kashmir), India.

(Corresponding author: Sunil Dhar)
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ABSTRACT: Any change in the climatic conditions can be manifested by the glacier which helps in understanding the prevailing trend of climate and anticipating scenarios of the future. Study of glacier is important because as the glaciers point out the evidences and impact of climate change. Changes in mass, volume, area, and length of Indian Himalayan glaciers are major indicators of global warming and climate change at regional level, which hamper downstream water availability and natural hazards (GLOF) in the river basins of the Himalaya. The study is an attempt to understand the status of major glaciers in Chandra basin with use of multispectral satellite datasets. Glaciers in study area shows average rise in the ELA as about 53m/yr for the period of 1980-2011. This is significant as it goes onto show that keeping in view the size of smaller glaciers (up to 3 km^2) their melting trends are on the higher side as compared to bigger glaciers.This effect has permeated into the higher value of deglaciation (19.32%) in the last three decades for the glaciers of Chandra basin investigated under the present study. The observation further point out to the fast melting of glaciers ever since the beginning of twenty-first century in Lahaul – Spiti region of Himachal Pradesh.

Keywords: Climate Change, Chandra Basin, Deglacition, ELA, GLOF, Himalaya.

I. INTRODUCTION

The Great Himalaya, youngest mountain range in the globe which separates India from China along the north-central & eastern frontier. The Himalayan range extends within 26°20' - 35°40' N latitudes & 74°50' - 95°40' E longitudes [1]. The Trans-Himalaya and Himalaya constitute 50% area of glaciers outside of the poles [2]. Indian Himalaya incorporates about 1400 km^3 of ice and snow [3] with 17% of mountain region in comparison to 2.2% in case of Alps [4]. Deglaciation in case of Himalayas is influenced by factors primarily regional and climatic; however the warming in the mountains because of increased emission of GHGs influence majorly. Geological Survey of India in recent inventory observed existence of 9,575 glaciers in the Indian region of Himalaya comprising the limits of Union Territory of Leh-Laddakh, J&K, State of Himachal Pradesh in the Western Himalaya, Sate of Uttarakhand & Sikkim (central Himalaya) and Arunachal Pradesh (Eastern Himalaya) (Fig.1). Himalayan mountain glaciers are unique with respect to their location, as they reside near to Tropic of Cancer and receive excess heat with respect to Antarctic, Arctic and other shield glaciers. Himalaya gives a unique opportunity to examine snout fluctuations, mass balance and area loss that further can be modelled for different climatic regimes.

Snout advances and retreat and changes in mass balance are a response to climatic fluctuations, as Glaciers shows more sensitivity to changes in climate. Glacial water because of ice and snow melt is a major contributor to the runoff of streams [5]. Freshwater reservoir health and climate change indications along with global worming are authenticated by glacial observations. Shrinking and repeated thinning of these fresh water reservoirs may lead to hazardous scenario which may cause disruption to ecological setup on the earth. Large retreat of glaciers is response to global warming that occurred over the globe [6]. Due to which Himalayan glaciers as because of their location in the mountainous zone receded considerably which hampered runoff of the Himalayan streams in the last century [7, 8]. Glaciers residing in the mountain regimes like Himalayas have depicted retreat and lost mass since mid-19th century [9] as rejoinder to the warming climate [10]. Whereas some glaciers in Karakoram region have advanced while many of them are stable in the last decade [11-14]. Annual retreat in Indian Himalayan glaciers varies from 16- 35 meters suggesting that most of the glaciers are in retreating stage as deciphered in many pre-investigations [15, 16]. Repeated glaciations period encompassing a huge land mass, in the Pleistocene was experienced on the earth's surface. Glaciations occupied an area of 46 million km^2 during its peak, which was three times larger than the present ice mass on the globe; the reasons could be the earth's orbital variation and differences in packages of solar radiation received in different regions. [17]. Global temperatures are presently 5ºC more than the last peak glaciations period. Approximately 33,000 sq. km landmass in the Himalaya, contain major volume of glacier water placed outside the polar zones in the globe and it is the base of major river water systems which flourish civilizations along the banks of rivers.

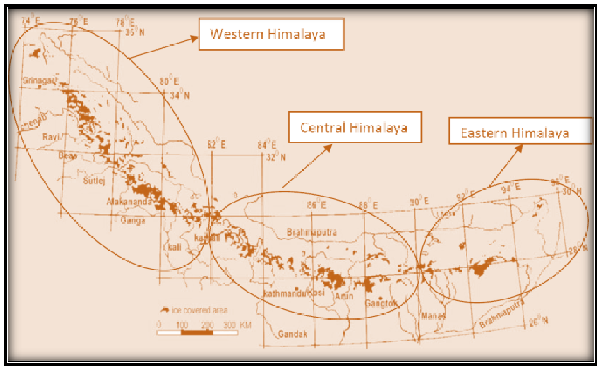

Fig. 1. Glaciers distribution and division of the Himalayas [18].

II. STUDY AREA

Chandra-Bhaga basin located in the North of Great Himalayan range and with Pir-Pangal range in South occupies an area of 7510 km^2 and is largest among other basins in Himachal Pradesh. The Great Himalayan range is an orographic barrier which shields the region from the monsoon and creates a shadow zone. More than two hundred glaciers have been identified in this basin, of which 43 lies on its southern side (Pir-Panjal range) and flow into the mainstream of the Chandra-Bhaga River where as on its northern side 157 glaciers of different orientations have been recognized flowing into the main river Chandra-Bhaga (Fig. 2). The study emphases on the major glaciers located in Chandra Basin of Himachal Pradesh.

Study area of Chandra basin lies within 32º10' - 32º85' N latitudes and 77 º 00' - 77º 75' E longitudes. The Chandra basin experience snowfall in the winter season (ONDJFM) and rainfall during the summer season (AMJJAS). Glaciers of Chandra basin gain mass because of the snowfall, avalanching and blowing snow. River Chandra originates from the Greater Himalayas and unites with River Bhaga at Tandi, Lahaul-Spiti, Himachal Pradesh (Fig 3). The Chandra river basin is distributed in SOI topographical map nos. 52H/3, 52H/4, 52H/7, 52H/8, 52H/10, 52H/11, 52H/12, 52H/15, 52H/16, 52D/14 and 52D/15.

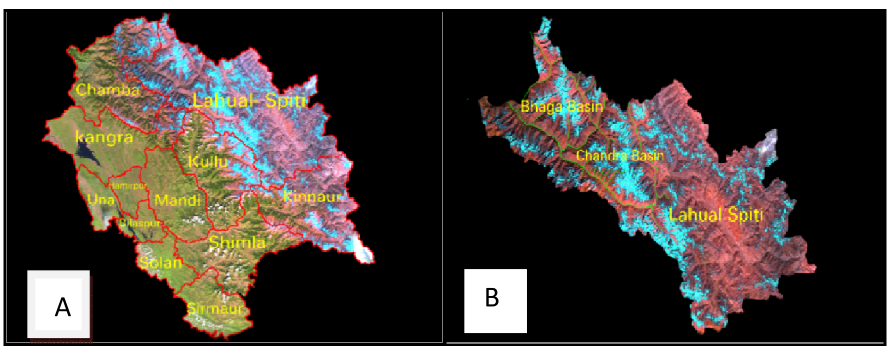

Fig. 2. (A) District map of Himachal Pradesh. (B) Basin map of Chandra-Bhaga basin/s, Lahaul- Spiti district, Himachal Pradesh.

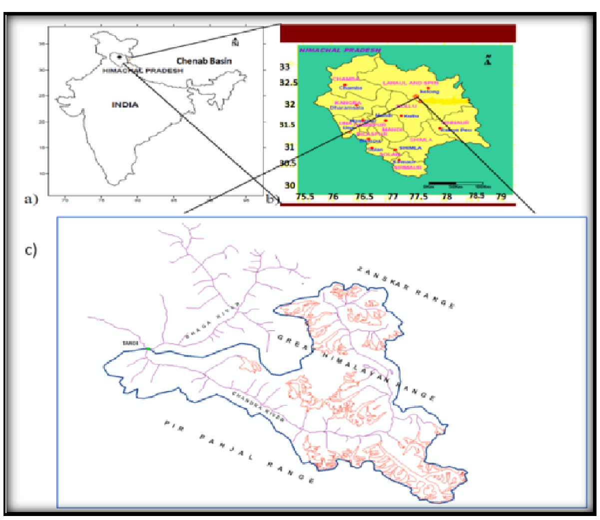

Fig. 3 (a) Location map of Chandra basin, (b) Basin boundary of Chandra catchment, Himalayan ranges and (c) Glacial cover as seen in the Chandra basin.

Bara Shigri is one of the largest glacier with 29 km length and 157 km^2 area in the Chandra basin. The other glaciers are SamudraTapu (18 km), Mulkila Gang glacier (13.25 km), ChhotaShigri (9 km) Gepang Gath (5.5 km), Batal glacier (6.3 km) and Miyar (25 km). The variations in the length of the glaciers are within the limits of 0.8 km to 29 km but the length of several glaciers (about 35%) range from 2 to 4 km. The maximum spread of glaciers is up to a height of 6632 m (MSL), while the minimum has been observed at 4410m. These glaciers are in medium-low latitude and high in altitude which is above 4000m. (Fig. 4).

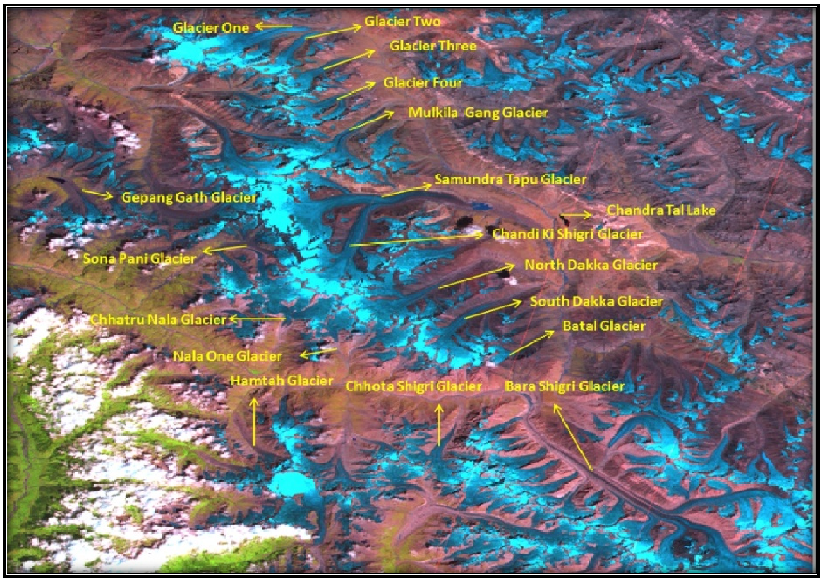

Fig. 4. Glaciers of Chandra Basin (conventional names).

III. DATA TYPE AND METHODOLOGY

The study was carried out using data sets from the Indian and foreign Satellite programs IRS and Landsat. Landsat Thematic Mapper (TM), LISS-III (IRS-1D) and LISS-IV (IRS-P6) data sets were explored for the mapping of the glaciers. The selection of datasets was done on the basis of minimum cloud cover, snow influence on the study area. IRS-P6 (launched on 17 October 2003) and Remote Sensing imagery of Chandra basin was selected for the month of July–September period seeing the convenience of minimum snow cover and full exposure of glaciers. LISS- IV sensor is of 5.8 m resolution with three bands and is used for the monitoring of glaciers and ice fields. Therefore, this sensor can be used to monitor small glaciers and ice fields Glacial extent mapping for the consecutive years 1980, 2001, 2007 and 2011 was done using the Landsat TM data for the year 1980, LISS-III data for the year 2001, and LISS-IV data for the year 2007 and 2011. Remote Sensing images were Ortho-rectified in the ERDAS Imagine software and the image preprocessing procedures were applied in the GIS environment. Glacial boundaries were marked on the georeferenced and Ortho-rectified remote sensing images by applying different band combinations and enhancement techniques for the delineation of the glacial boundaries in the GIS platforms. Vector layers encompassing the extent of the glaciers for the subsequent years were prepared and overlay analysis in the GIS environment was examined to access changes in the area and equilibrium line fluctuations of the glaciers of the Chandra basin from during the period 1980 to 2011.

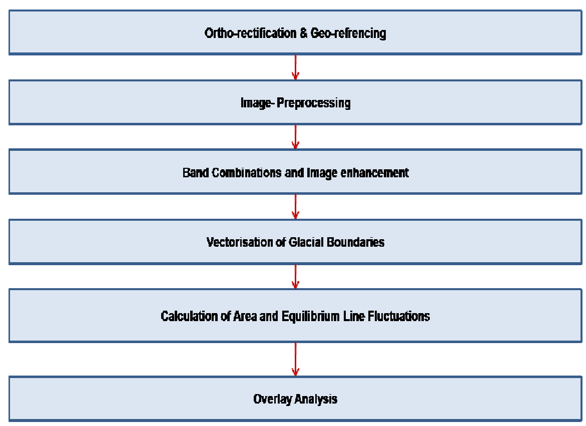

Fig. 5. Research methodology adopted for the study area.

IV. RESULT AND DISCUSSION

Landuse/Landcover of Chenab Basin: On analyzing the satellite data, it was observed that the predominant land cover available in the Chandra basin is stony waste or barren rock surface that constitute about 24.82% of the total catchment area. The other categories available in the catchment are Agriculture 0.73%, total forest land 6.37%,Area under snow cover 27.01%,surface drainage/stream 1.02%, glacial lakes 0.12%of the total catchment area. The barren rock surfaces are characterized by the predominance of scree material which is mainly due to high freezing condition leading to have frost and thaw activities resulting in the breaking of rock masses. In the higher regions, the scree deposits conceal beneath them the permafrost terrain during the whole year. (Table 1)

Table 1: Land use of Chandra catchment, Lahaul-Spiti, H.P.

S.No.	Land use/Cover Categories	Total Area (Km^2)	%age of the total Catchment Area
1.	Stream	25.49	1.02
2.	Agriculture	18.34	0.73
3.	Forest/Shrubs	158.19	6.37
4.	Snow/Ice Cover	670.27	27.01
5.	Rocky land	615.94	24.82
6.	Lakes	3.03	0.12
7.	Watershed	2480.76	

Equilibrium Line Altitude (ELA) fluctuation between 1980 to 2011 in Chandra Basin: ELA (Equilibrium-line altitude) signifies the zone which separates the accumulation zone from ablation zone on glacier where annual ablation and accumulation are same. ELA is closely related to the local climate and it is the location where net mass balance is zero. As ELA increases, glacier retreats because most of the glacier lies in ablation area where as glacier advances as the ELA decreases.ELA observations within the time interval of 1980 -2011 for 22 significant glaciers of the region confirm the rise in the elevation of ELA. The average observation of the ELA is 5220.90, 5251.68, 5261.59 and 5273.45 meters for the years 1980, 2001, 2007 and 2011 respectively. The average rise of about 53 meters has been observed in 31 years in the region. Further, the average altitude of ELA towards the south of Great Himalayan Range is at 5325.14 meters and in the North of Great Himalayan Range is observed to be at 5192.66 meters and further north of Great Himalayan Range the value stands at 5080 meters. Glaciers situated further north of Great Himalayan Range, because of higher altitude probably explains the higher altitudinal position of ELA of the glaciers in this region of Chandra basin. Moreover, individual glaciers behave differently due to the factors other than climate, such as slope/aspect, Bed topography, shape and size, and the orientation of the glaciers.

Glacial Changes in the Chandra Basin: To understand glacial changes in Chandra basin 65 glaciers were selected for the study. Mainly the study was carried out concerning the base data of the year 1980. The base layer was correlated with the layers of the year 2001 and the year 2011. The objective was to map the changes for the last three decades as well as to assess the comparison between the periods of 1980-2001 and the period of 2001 and 2011. The glaciers that were investigated are given in Fig. 6.

Deglaciation % in Chandra Basin during 1980-2011: In Chandra Basin, all the glaciers have diminished in size. As most the glaciers including the Samundra Tapu glacier there is a hint of quantum of deglaciation to have picked up from 2001 onwards. However in glaciers like North Dakka, Chattru, Gepang Gath, Batal and South Dakka this trend is not visible. Percentage of the vacated area and deglaciation % for all the glaciers that have been studied is given in the (Table 2).

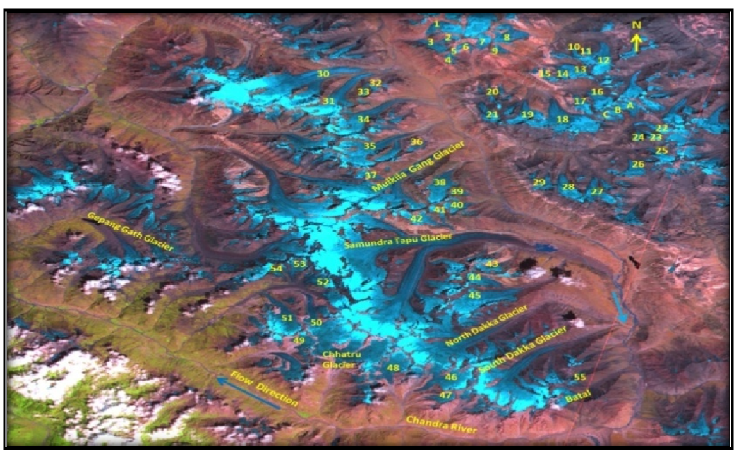

Fig. 6. Glaciers of Chandra basin taken up for the study.

Table 2: Glacial Fluctuations in Chandra Basin (1980-2001- 2011).

Glacier Name/Number	Area 1980(km^2)	Area 2001(km^2)	Area 2011(km^2)	Total Vacated Area1980-2011 (km^2)	Deglaciatio n %	Orientation
1	3.02	2.95	2.44	0.58	19.20	SW
2	0.95	0.85	0.64	0.32	33.68	W
3	1.74	1.62	1.42	0.31	17.81	W
4	0.34	0.29	0.17	0.17	50	E
5	0.82	0.66	0.42	0.4	48.78	E
6	0.94	0.79	0.56	0.37	39.36	S
7	1.81	1.45	1.2	0.61	33.70	S
8	3.87	3.56	2.9	0.97	25.06	E
9	0.82	0.72	0.58	0.25	30.48	E
10	0.87	0.66	0.46	0.41	47.12	N
11	0.64	0.6	0.47	0.17	26.56	N

12	4.86	4.46	3.85	1.01	20.78	N
13	*	2.01	1.87	*	*	W
14	*	0.72	0.63	*	*	W
15	0.98	0.8	0.58	0.4	40.81	N
16	2.65	2.42	2.11	0.53	20	NW
17	1.94	1.74	1.52	0.42	21.65	NW
18	10.01	8.92	7.65	2.36	23.57	NW
19	3.47	3.02	2.54	0.93	26.80	NW
20	2.24	2.06	1.62	0.62	27.67	NW
21	0.75	0.64	0.42	0.33	44	NW
A	2.6	2.39	1.95	0.65	25	S
B	0.97	0.87	0.74	0.24	24.74	S
C	0.71	0.64	0.52	0.19	26.76	S
22	1.62	1.48	1.24	0.39	24.07	W
23	*	0.47	0.41	*	*	W
24	*	0.54	0.37	*	*	W
25	1.76	1.57	1.35	0.41	23.30	NW
26	2.31	2.02	1. 80	0.51	22.07	NW
27	3.59	3.22	2.85	0.74	20.61	NW
28	3.24	3.04	2.63	0.6	18.51	NW
29	1.58	1.39	0.96	0.62	39.24	NW
30	17.7	16.28	14.32	3.39	19.15	NE
31	7.76	6.81	5.29	2.47	31.83	NE
32	0.51	0.43	0.32	0.19	37.25	NE
33	0.59	0.53	0.41	0.18	30.50	NE
34	8.26	7.37	6	2.26	27.36	NE
35	10.11	9.22	7.78	2.34	23.14	NE
36	0.79	0.65	0.52	0.27	34.17	NE
37	1.63	1.31	1.1	0.53	32.51	NE
Mulkila Gang	15.14	14.11	12.19	2.95	19.5	NE
38	4.82	4.56	4.18	0.64	13.28	NE
39	0.74	0.69	0.49	0.26	35.13	E
40	2.2	1.85	1.54	0.66	30	E
41	1.1	0.98	0.85	0.25	22.72	SE
42	3.06	2.78	2.38	0.69	22.55	SE
SamundraTapu	84.06	80.41	74.42	9.65	11.48	E
43	2.03	1.72	1.41	0.62	30.54	NE
44	2.52	2.33	2.1	0.43	17.06	SE
45	8	7.67	7.09	0.91	11.37	NE
North Dakka	25.69	22.96	20.34	5.35	20.82	NE
46	7.55	6.76	6.45	1.1	14.57	SW
47	*	1.52	1.43	*	*	SW
48	7.65	6.51	6.5	1.15	15.03	SE
Chattru	14.21	12.84	11.49	2.71	19.07	S
49	3	2.63	2.22	0.78	26	SW
50	11.55	10.05	9.04	2.51	21.73	SW
51	7.22	6.38	5.77	1.46	20.22	SW
52	8.04	7.57	6.56	1.48	18.40	SW
53	2.38	2.12	1.82	0.57	23.95	S
54	4.24	3.78	3.6	0.64	15.1	S
Gepang Gath	13.8	12.23	10.94	2.86	20.73	E
55	0.52	0.3	0.22	0.3	57.7	
Batal	6.97	5.28	4.82	2.15	30.85	
South Dakka	23.56	20.51	19.63	3.93	16.7	
Total	**368.52 km^2**	**339.71 km^2**	**300.29 km^2**	**71.2 km^2**	**19.32 %**	

*Data absent for glacier nos.13, 14, 23, 24 and 47 (1980)

In terms of the percentage of deglaciation there is visible hint that the glaciers of smaller size up to 3 km^2 area decipher higher percentage of deglacition than the larger glaciers. Graphical representation which is indicative about the rate of deglaciation during different years becomes visible in the (Fig. 7). Out of the total degalaciation (1980-2011), majority of the glaciers have vacated faster during 2001-2011 with respect to 1980-2001. Predominant of glaciers shows deglaciation % in the range of 20-30% during 2001-2011 against 10-20% during the two decades of 1980-2001. The overall picture that has emerged reveals deglaciation of almost 11% during the time span of 1980-2001(twenty years) whereas this figure stand higher at about 16% during the time span of ten years (2001-2011). This also means that the deglaciation increased by one and a half times during 2001-2011 as compared 1980- 2001 or in other words the values of deglaciation during the ten years of 2001-2011 is 1.5 times more than the deglaciation value observed for twenty one years between 1980-2001.

The behaviour of the glaciers for different years in Chenab Basin: To understand the glacial changes that have occurred in the Chandra basin for 1980, 2001, 2007 and 2011, 65 glaciers have been categorized according to their size so that trend in the change of the glacial area becomes more visible. Selected 65 Glaciers in Chandra basin shows 19.5 % deglaciation from 1980 through 2011. Glacial Changes for 1980, 2001, 2007and 2011 is shown in Fig. 8.

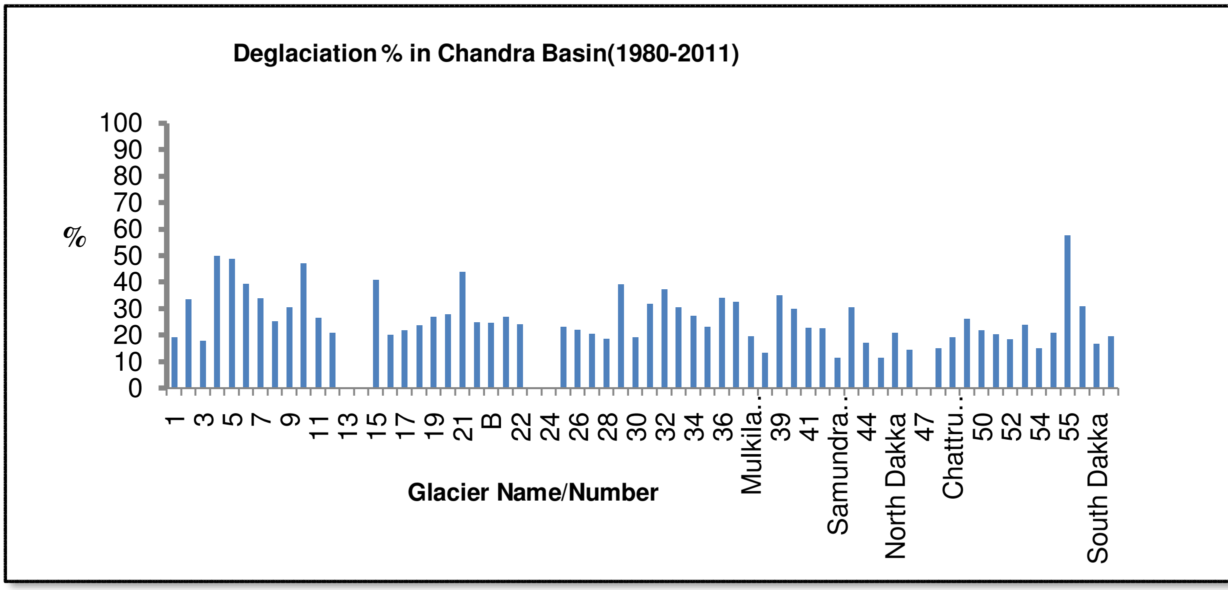

Fig. 7. Deglaciaion % in Chandra Basin from 1980 to 2011**.**

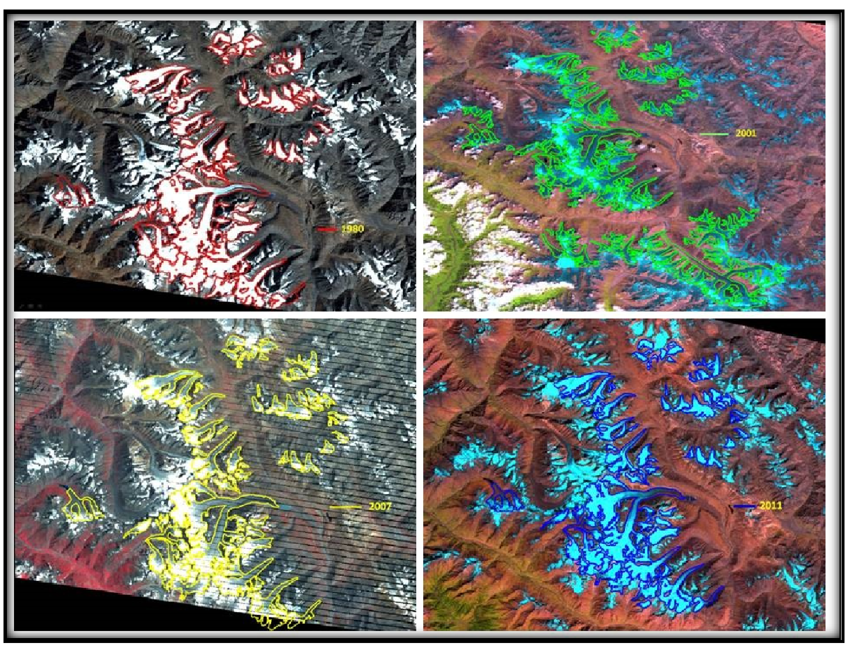

Fig. 8. Glacial change for 1980, 2001, 2007, 2011.

Most Glaciers up to the size of 5 km^2 shows decreases in the area up to the order of 1 km^2 for the last three decades. However, the glaciers which exceed in areal extent from 5 km^2 and above show the decrease in their area several times higher than the smaller glaciers. After analysing statistically we categorised all 65 glaciers based on their areal extent for 1980, 2001, 2007, and 2011 which showed in Table 3.

Table 3: Statistical summary of number of glaciers in the year 1980-2011 under different classes of their size in the Chandra basin.

Glacier Area (km^2)	Glaciers in 1980	Glaciers in 2001	Glaciers in 2007	Glaciers in 2011
0 – 1	16	20	20	20
1 – 3	17	20	23	24
3 – 5	09	07	03	04
5 – 10	08	10	09	10
>10	10	08	07	07
No Data	05	Nil	03	Nil
Total	**65**	**65**	**65**	**65**

After analyzing the results of Table 02 & 03, in 1980, of the total glacial area of 368.50km^2 glacial area has shrunk to 339.71, 300.67, 300.29 km^2 in 2001, 2007 and 2011 years respectively. The vacated area is estimated at 71.2 km^2 in between 1980-2011, which accountfor 19.32% deglaciation in Chandra basin. As far as the aerial distribution of these 65 glaciers is concerned, majority of glaciers falls in the category of small glaciers in which the area ranges between 1-3 km^2, followed by much smaller glaciers within aerial range of 0-1 km^2. (Table 3). Number of such smaller glaciers has remained the same during the monitoring years however the glacial cover in this category has diminished from 11.95 km^2 in 1980 to 9.78 km^2 in 2011. Glaciers falling in size between 1-3 km^2 have increased in number from 17 in 1980 to 24 in the year 2011. 09 glaciers were mapped on the data of 1980 and having size between 3 to 5 km^2 which reduced to 4 by the year 2011. Number of glaciers in the category 5-10 km^2 has risen from 8 in 1980 to 10 in the year 2011. The reason being that two glaciers from the above 10 km^2 category jumping into this category between the monitoring years of 1980-2011.10 glaciers of the size more than 10 km^2 were mapped in 1980 with an aerial extent of 225.83 km^2 which have reduced to 07 (163.33 km^2) in 2011.

Variation in Temperature and precipitation during Accumulation and Ablation month in Lahaul-Spiti District, Himachal Pradesh: Lahual-Spiti is the district of Himachal Pradesh, lying in Western Himalaya which has dominance effect of both Westerlies Disturbances and Indian summer monsoon, is a glacierized area with 13 % debris covered. In Lahaul-Spiti region, Accumulation Month interval is taken from October to March and subsequently ablation month interval is from April to September to examine the trend of temperature and precipitation change in the area. During June to august months, region experience major precipitation with slight snow due to warming temperature. Many researchers attempted to address the region as being the largest glaciated zone for the analysis of terminus variation, area change, mass balance and surface velocity etc. Temperature of the Himachal Pradesh region is escalating and simultaneously precipitation is declining on the basis of different previous studies. As precipitation and Temperature are two key leading factors of the glacier health. As compare to precipitation, temperature changes prominently influence the glacier surface. Glaciers located in the Lahaul-Spiti region are losing mass due to changes in weather patterns. Analysis of temperature trends based on 125 stations located throughout India, evidence an increase of 0.09ºC, 0.92ºC and 0.42ºC in mean minimum temperature, mean maximum temperature and annual mean temperature over the period of last 100 years respectively [19].

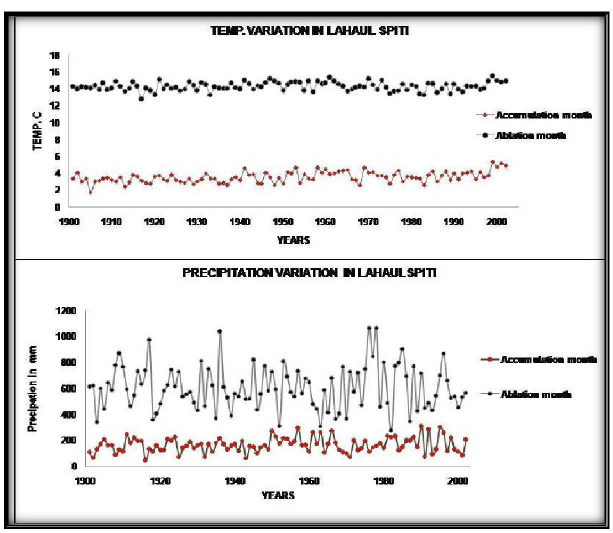

Fig. 9. Temperature and Precipitation variation during Accu.month(ONDJFM)and Abla. Month (AMJJAS) in LahaulSpiti District H.P. between 1901-2002. *(Source http://www.indiawaterportal.org/met_data/)*

V. CONCLUSION

It was observed from the satellite data that the predominant land cover in Chandra basin is snow cover area (27.01%) and stony waste or barren rock surface (24.82%). In Chandra basin monitored glaciers shows rise in the ELA between periods of 1980-2011 which clearly indicate glacier retreat. The average rise of about 53m has been observed in 31 years in the study area. However individual glaciers in the basin respond differently. This is significant as it goes onto show that keeping in view the size of smaller glaciers (up to 3 km^2) their melting trends are on the higher side as compared to bigger glaciers. There can be number of reason that can be accredited with fast melting of glaciers with smaller sizes include: (a) their debris-free attitude. (b) Local geomorphology especially the slope conditions. (c) Local geology/ bedrock on which these glaciers have formed. The higher value of deglaciation (19.32%) as deciphered is a result of the fast melting in the case of small glaciers with respect to the larger ones. If the effects of small glaciers are removed from the form in the analysis the deglaciation valves hover at around under (10%) in the last three decades. Glaciers like Samundra Tapu shows rapid deglaciation from 2001 however North Dakka, Chattru, Gepang Gath, Batal does not show this trend, because of the existence of lakes (moraine-dammed) at their snout/s. Study suggests that the deglaciation increased by one and a half times during 2001-2011 as compared to 1980-2001 in Chandra Basin. More detailed quantitative case studies and field based investigations for the better understanding of glacial response to the climate change are required in the study area.

VI. FUTURE SCOPE

Glacier study in the Indian Himalayan range is very necessary for the livelihood of local community living there as well as for regions in the downstream areas. Indian Himalayan region is prone to the natural hazard like Glacier lake outburst flood (GLOF) and glacier like Samundra Tapu and Gepang Gath glacier have the enlarging moraine dammed lake near the snout which may pose threat in times to come. The present study is primarily based on the remote sensing dataset for more than 60 small and big glaciers in Chandra basin which clearly indicates that most of the glaciers are receding at a faster and alarming rate. To understand precisely the reasons of differential retreat of glaciers in the Chandra basin, it is intended to study some selected benchmark glaciers of the basin in terms of glacial change, development of moraine dammed lakes and Peri-glacial geomorphology.

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Conflict of Interest. No conflict of interest among Authors.

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