Asian Journal of Science and Applied Technology
ISSN: 2249-0698 (P) Vol.7 No.1, 2018, pp.1-7

DOI: https://doi.org/10.51983/ajsat-2018.7.1.1027

Determination of Glacier Mass Balance using Remote Sensing and GIS Technology: A Case Study of Bara Shigri Glacier, Himachal Pradesh

Priyanko Das[1] and Manish Rai[2]
[1]Department of Geography, University of Madras, Chennai, Tamil Nadu, India
[2]India Meteorological Department, Shimla, Himachal Pradesh, India
E-Mail: piyanku.2012@gmail.com, manishrai.imd@gmail.com
(Received 8 December 2017; Revised 27 December 2017; Accepted 19 January 2018; Available online 25 January 2018)

Abstract - **Glaciers plays a major role in the generation of stream flows in Himalayan region. The Historical studies say that many glaciers in the Himalayan region are retreating due to climate change and global warming. It is important to study of glacier as they are the main source of fresh water. Due to change of climate over different time periods there is a continuous decrease of glacier areas. So it is now a days become very big issue for our future as well as present generation for fluctuation of fresh drinking water storage. The present study focuses to examine the changes in snow-covered area and glacier mass balance of the Bara Shigri glacier of Himalayan region using Remote Sensing and GIS technology. Remote sensing technique can be used without any restrictions of manual approach. The study aim is to show the changes of snow cover area and mass balance of glacier during last 27 years from 1989 to 2016. Snow cover area has been monitored using imageries of Landsat-2 and Landsat-5 multispectral band (1989, 2002, 2008, and 2016) TM and ETM data using NDSI (Normalized Difference Snow Index), NDSI-2(Normalized Difference Snow Index-2), NDGI (Normalized Difference Glacier Index), and Band ratio techniques. WGMS (World Glacier Monitoring Services) data are used for accuracy assessment for the Mass balance, front variation and annual thickness in the glacier for analyzing the surface – atmosphere interaction which contributes to melting of the glacier.**
Keywords: **NDSI, NDSI -2, NDGI, Band Ratio, WGMS data, Glacier Mass Balance**

I. INTRODUCTION

Glaciers and snow cover play a major role in the dynamics of the climatology and it has been changing rapidly especially during the past century. From the hydrological perspective, the change in glacial and snow cover area is an important indicator of climate change. Glaciers are the most important source of fresh water and stream flows. Understanding the glacial melting rate is important for estimation and management of water resources (Hamlet and Lettenmaier, 1999; Marsh 1999), the total glaciated area of the world is about 14.9 million sq. km. Out of this 12.5 million sq. km is located in Antarctic and 1.7 million sq. km is in the Greenland and the Indian Himalayas cover almost 23000 sq. km of glacier area. The study is focused on changing Snow cover area during the past few years in Bara Shigri glacier and its relation to climate change.

Bara Shigri glacier is 25 km long and 3km wide glacier and is the second longest glacier in the Himalayas after Gangotri. The Bara Shigri means big glacier which is located nearby Chandra valley of Lahaul. Global climate change interacts sensitively with mountain glaciers. Recent research has shown that the glaciers in the Bara Shigri are shrinking at rather fast rates. According to the IPCC report, global temperatures have increased by about 0.89^0C over the period 1901-2012. This study proposed to study the glacier change under the changing climate pattern in the Lahaul - Spiti region. Very less research has been done on the distribution of snow cover area in this region. The Remote Sensing technique is used worldwide and it’s an excellent choice for analyzing the snow cover changes in mountainous regions. It can save money and time. Much work has been done to analyze glacier change using Landsat-2 and Landsat-5 TM and ETM data. The number of methods for glacier mapping, such as Visual interpretation, Band ratio, Normalized Difference Snow Index (NDSI), Normalized Difference Snow Index-2 (NDSI-2) and NDGI (Normalized Difference Glacier Index).

The study has compared different maps which are generated by satellite image data. WGMS data is used for analyzing the Mass balance, Front variation and annual thickness of this region. Annual thickness data is used to assess the change in snow-covered area in this region for understanding the increase in temperature during the past few years, which is the cause of glacier melting.

II. LITERATURE REVIEW

Hamlet *et al,* (1999) conduct a comparative research work on climate change on hydrology and water resource in Columbia River basin. The study was based on global climate model and GCM simulation. Decadal mean temperature and precipitation data used to create inferred condition for 2025, 2045 and 2095. These records represent future climate perspective. The research work shows Different seasonal pattern for temperature change and the simulation show increases temperature of about 1.8 – 2.1°C for 2025. Although the HC simulations predict an annual temperature increase of about 4.5°C for 2095. These changes in stream flow create increase water flow during the spring, summer and early fall. In case in the simulation for 2045 the annual runoff volumes range is 85 percent to110 percent.

Haq *et al,* (2011) made a study on glacier monitoring of Gangotri glacier using satellite imagery. This paper presents the results, which is obtaining from multitemporal Landsat imagery. The research work is based on Landsat and DEM imagery datasets. Satellite data of Landsat 1972, 1976, 1990, 2000 and 2010 were used for investigation. The study was carried out Glacier mass balance using Band ratio and AAR method. The AAR (Accumulation Area Ratio) was also estimated using band ratio techniques. The research work has shown an overall reduction in glacier area during the study period.

Kulkarni *et. al,* (2002) carried their research work on field based spectral reflectance to developed NDSI (Normalized Difference Snow Index) method for snow cover monitoring. The research work is based on the high reflectance of snow in the visible region and its low reflectance in the SWIR region.

The reflectance value used for developed NDSI method Himachal Pradesh. Three field radiometer were used for ground data collection. NDSI values from all types of snow cover area have been found in the range of 0.9 to 0.96. NDSI values from other feature (soil, vegetation and rock) were sustainability different compare with snow. Although the study was found that the water body has closed to NDSI values and they need to be masked during the snow cover delineation.

Most of the studies were used Landsat Satellite imagery for glacier monitoring and glacier mass balance Sukla (2011), Keshri et al. (1989), Hall et al. (1995). The study is based on glacier fluctuation and decreasing rate of snow cover area, which is indicate the climate change impact on our earth system.

II. STUDY AREA

Geographically, Bara Shigri glacier is located at Lat. 320 09’ 52’’ N and Long. 770 41’ 15’’ E. The Glacier has been situated near the Chandra river basin, nearby Chandra valley on the northern ridge of Pir-Panjal range in the Lahaul – Spiti valley of Himachal Pradesh, India. Bara Shigri glacier is at an elevation of 6637 m above MSL (mean sea level) and catchment area lies in ESE-NNW direction. Good vegetation is found in lower parts of the study area and during the summer season, 50% area is snow cover free.

III. METHODOLOGY

Different satellite data has been used to determine the snow cover area and glacier mass balance of this region. The Landsat image is taken from the USGS website and Bara Shigri glacier outline is taken from the WGMS website. The several algorithms (NDSI, NDSI-2, NDGI, and Band Ratio) was used to estimation the Glacier area change and Mass balance. After estimated Different Method the showing different Changes of this region in Different years. The Changes (Changes 1, 2, 3, 4, and 5) has been comparing and give a final output of this research work. Figure 2 is showing the flowchart of the methodology.

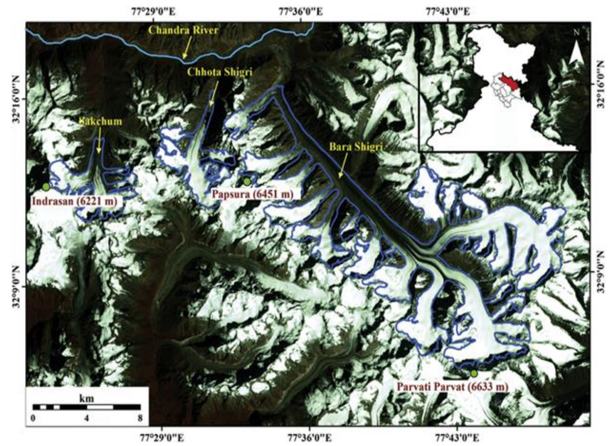

Fig. 1 Bara Shigri Glacier

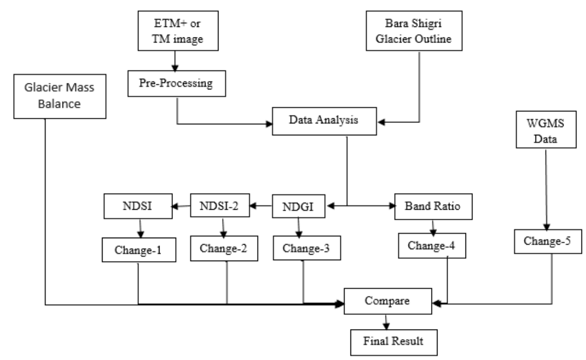

Fig. 2 flow chart of methodology

IV. DATA SOURCE

Different types of satellite imagery data are available on different spectral resolutions – up to 200 spectral wavebands between 0.4 µm to 2.5 µm. For this study, Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) imagery are used. More information about data used is given in table no 1. After preprocessing, four methods NDSI, NDSI-2, NDGI and Band Ratio were used to differentiate the glacier outlines. NDSI and Band Ratio images were segmented into two classes- “glacier” and “other”. WGMS was used to correlate with our research work.

TABLE I DATA SOURCE OF SATELLITE IMAGERY IN THIS RESEARCH WORK

Time	Satellite	Sensor	Path – Raw	Resolution (m)
1989/10/09	Landsat 5	TM	147-38	30
2002/10/18	Landsat 7	ETM^{+}	147-38	30
2008/10/13	Landsat 5	TM	147-38	30
2016/10/03	Landsat 5	TM	147-38	30

V. SPECTRAL REFLECTANCE OF SNOW IN LANDSAT TM BANDS

The spectral reflectance of snow and ice covered area is modeled as multiple scattering problems (J. G. CORRIPIO.DECEMBER, 2004). Snow is highly transparent at visible wavelengths and the near- infrared wavelength is more absorptive. We can easily differentiate spectral reflectance of snow cover area and non-snow area using spectral profile of Landsat 5 TM (fig.no 3, 4, 5). Spectral reflectance is high in snow cover area and low in the non-snow cover area.

VI. SPECTRAL PROFILE

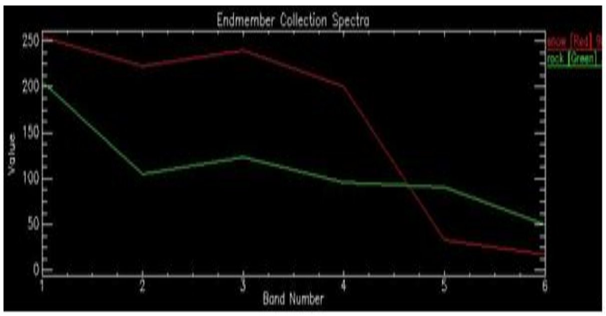

Fig. 3 reflectance of snow and non-snow covered area

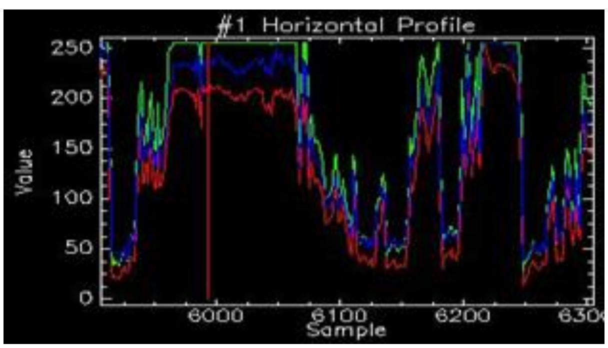

Fig. 4 Horizontal reflectance

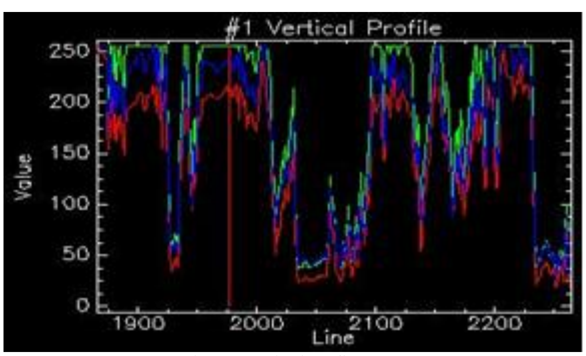

Fig. 5 Vertical Reflectance

VII. DIFFERENT METHODS OF GLACIAL MAPPING-

A. NDSI (Normalized Difference Snow Index)

The spectral reflectance of snow is high in the optical region of the electromagnetic spectrum and snow reflectance is low in SWIR region (Figure.2, 3, 4). This characteristic has been used to generate a Normalized Difference Snow Index (NDSI) for snow mapping (Aparna Shukla, 2011). Ice in glacier has high reflectance in red (600-700 nm) as well as blue (400 -500 nm) and green (500-600 nm) wavelength. The spectral reflectance properties of snow are depending on time and season of the year. Albedo is high (0.8-0.97) in fresh snow and low (0.15-0.25) in dirty ice. NDSI is calculated as the difference between the strong reflectance of visible radiation (red) and near total absorption of Mid-IR wavelengths (Hall et al.1995 a). NDSI is estimated by comparing Digital Numbers of following TM bands of

Landsat-5 using following equation –

$$\text{NDSI}=\left(\frac{\text{Red band-SWIR Band}}{\text{Red band +SWIR Band}}\right)$$

$$\text{NDSI}=\left(\frac{\text{TM3-TM5}}{\text{TM3 +TM5}}\right)$$

NDSI reflectance value for rock and vegetation are negative, for clouds it is close to 0.2 and for snow, it is above 0.4 (Kulkarni et al. 2002). For analyzing the NDSI values. The data from years 1989, 2002, 2008 and 2016 has been used.

B. NDSI-2 (Normalized Difference Snow Index)

According to Dozier (1989), Hall et al. (1995b) they developed a new snow mapping technique for differentiation of snow – ice-covered areas from non-snow and ice areas. This NDSI product uses the shortwave infrared and green spectral bands from various satellites (Landsat-5 TM, Landsat – 7 ETM). The snow absorbs most of the shortwave radiance from the sun but the cloud does not. So, the NDSI can easily differentiate snow and cloud and it can be used, subsidiarity, in glacier monitoring. To estimate the NDSI following formula has been used:

$$\text{N SI 2}\ \left(\frac{\text{Green and SWIR and}}{\text{Green and SW IR and}}\right)$$

$$\text{N SI 2}\ \left(\frac{\text{TM3 TM5}}{\text{TM3 T M5}}\right)$$

C. NDGI (Normalized Difference Glacier Index)

The NDGI is an important indicator that helps to detect the snow-covered areas with the help of green and red spectral bands Keshri et al. (2009). It is used for snow mapping and is used to differentiate between snow- ice and mixed ice and debris class. To estimate the NDGI the following formula has been used –

$$\text{NDSI-2}=\left(\frac{\text{Green band-Red Band}}{\text{Green band +Red Band}}\right)$$

$$\text{NDSI-2}=\left(\frac{\text{TM2-TM3}}{\text{TM2 +TM3}}\right)$$

D. Band Ratio

Mapping of the snow-covered area using Remote Sensing technique is a difficult task because the glacier surface has a similar reflectance to surrounding cloudy areas in the Visible to Near-Infrared region so, sometimes NDSI could not be used accurately for snow mapping. Therefore, a new method was developed for glacier mapping.

The Band ratio image is the ratio of Near-Infrared (NIR) and Shortwave Infrared (SWIR). Thresholding of band ratio method is a better approach for mapping clean snow and ice mapping and its better performs then NDSI. Band ratio images were calculated using raster math tool in Arc GIS 10.3. To estimate the band ratio using Landsat imagery, the following formula has been used-

$$\text{and ratio } \left(\frac{\text{NIR}}{\text{SWIR}}\right)$$

$$\text{and Ratio } \left(\frac{\text{TM4}}{\text{TM5}}\right)$$

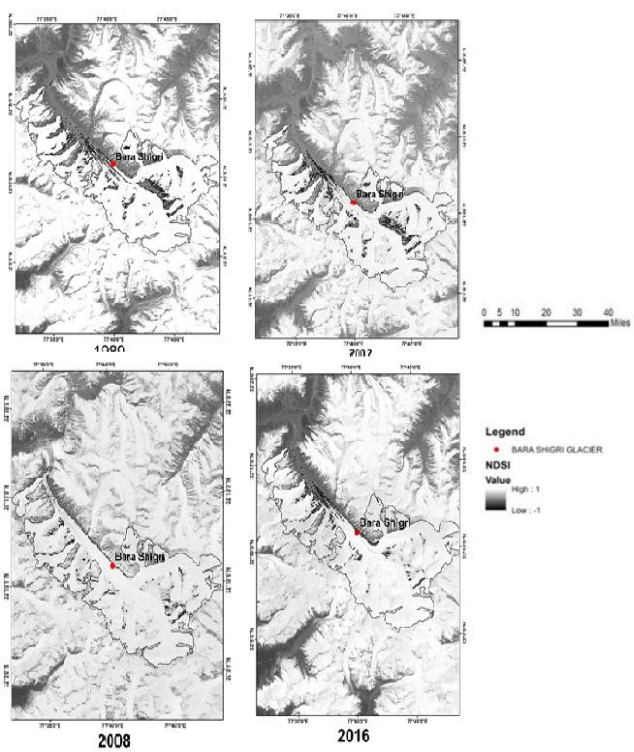

Fig. 6 Object-based analysis for detection of glacier melting and climate change on Bara Shigri glacier
NDSI (Normalized Difference Snow Index)

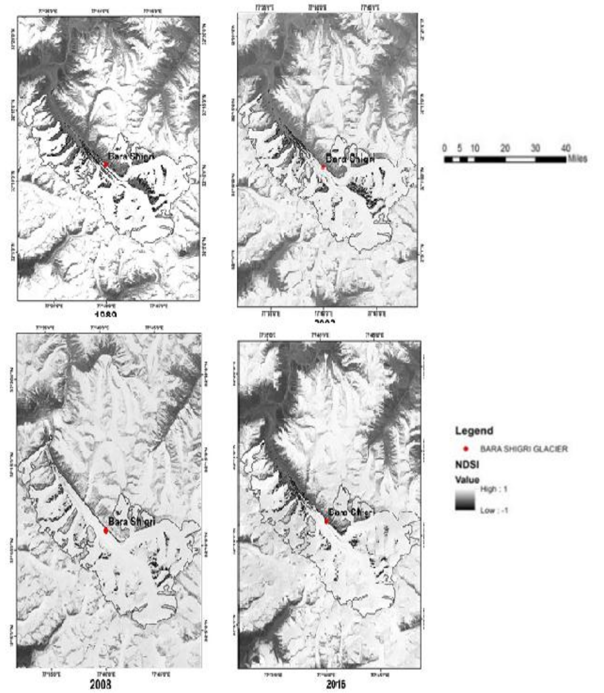

Fig. 7 Object-based analysis for detection of glacier melting and climate change on Bara Shigri glacier
NDSI-2 (Normalized Difference Snow Index)

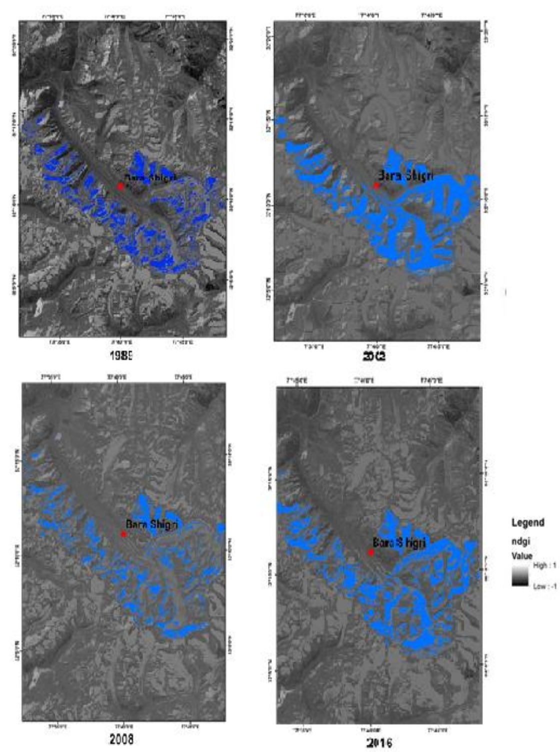

Fig. 8 Object-based analysis for detection of glacier melting and climate change on Bara Shigri glacier
NDGI (Normalized Difference Glacier Index)

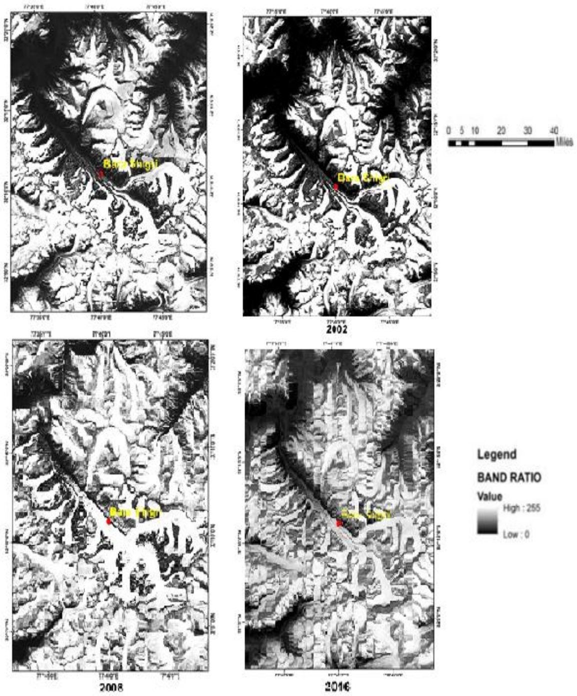

Fig. 9 Object-based analysis for detection of glacier melting and climate change on Bara Shigri glacier
Band Ratio

VIII. GLACIER MASS BALANCE

Glacier mass balance is the difference between accumulation and ablation (sublimation and melting) zones. Climate change may cause changes of the glacier mass balance. Mass balance of a glacier is the different between how much snow gains in the winter and how much snow melted over the summer. If the glacier exceeds out of the equilibrium, then it is positive and its retreat out of the equilibrium then it is negative. Glacier mass balance is a change in the mass of glacier body over a stated span of time (Summer school in Glaciology Fairbanks/McCarthy 7-17 June 2010) –Glacier front variation (Fig.no. -6) is measurement of snow out of a particular region. It’s an identification of glacier retreat over a period. The change in glacier front position is determined between two points in time (WGMS).and thicknesses of snow is about one half of the surface width of the glacier (Fig.no. -7). The Glacier thickness is more in winter and less in summer.

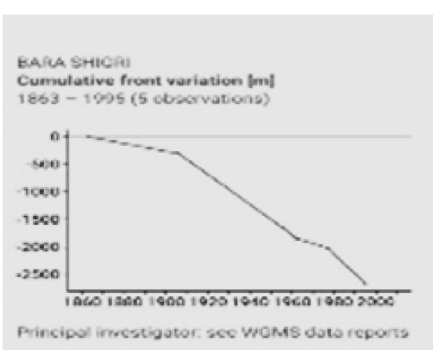

Fig. 10 Cumulative front variation

Hence, the WGMS (World Glacier Monitoring Services) data has been used to show the cumulative front variation [m] and ice thickness change in this region and compare it with results from Remote sensing techniques in this research work. ELA (Equilibrium line altitude) is a key measure of glacier mass balance and AAR (Accumulation area ratio).

The ELA line is a mixed zone for accumulation zone and ablation zone of the Glacier area. The ELA line found in ara Shigri glacier is 5200 MT’s a ove MSL (A. Jeyaram, Y.V.N. Krishna Murthy and D.S. Srinivasan). The ELA line upper part area of the glacier area is accumulation zone and lower part of the glacier area is Ablation zone where loss of mass is prominent. Band ratio image is associated with ASTER Digital Elevation Model (DEM) for glacier mapping, using band ratio method area of Glacier mass balance has been calculated.

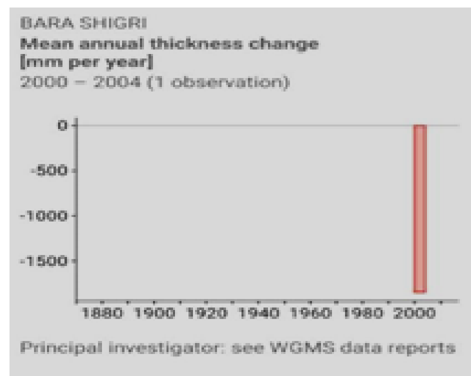

Fig. 11 Annual Thickness Change

ASTER DEM image used to estimate the Accumulation zone and Ablation zone. Accumulation area has been calculated (above 5200) in upper part of the glacier using DEM image. Ablation area is the difference between total area of the glacier and accumulation area of the glacier. Accumulation area ratio (AAR) is a ratio between accumulation area and total glacier area. AAR used to estimate using this formula. –

AAR = (accumulation area / total glacier area)

Glacier mass balance has been used to calculate with help of AAR. The following relationship used to measure the glacier mass balance (M Anul Haq, 2011) –

$$b= 243.01*X – 120.187$$

Where b is a glacier mass balance (cm) and X is the Accumulation Area Ratio.

Glacier area depth measured using total glacier area. The following formula used to measure glacier depth (M Anul Haq, 2011) -

H= -11.32 + 53.21 F 0.3

Where H is the main glacier depth (m) and F is the total glacier area (sq. Km).

TABLE II MEASURING THE CHARACTERISTICS OF BARA SHIGRI GLACIER

Year	Total Area (sq. km)	Accumulation Area (sq. km)	Ablation Area (sq. km)	Depth (m)	AAR	Mass balance (cm)
1989	133.15	90.53	42.62	219.51178	0.6799	-45.0354
2002	121.16	79.74	41.26	213.0687	0.6581	-39.7378
2008	155.89	90.89	65	230.6930	0.5830	-21.4878
2016	127.09	83.6	43.49	216.3085	0.6578	-39.6649

TABLE III ELEVATION AND TOPOGRAPHIC ANALYSIS OF BARA SHIGRI GLACIER

Characteristics of Bara Shigri Glacier	Aster DEM analysis
Min altitude	3950
Max Altitude	6637
relief	2687
ELA	5200
Aspect	ESE-NNW

IX. RESULTS AND DISCUSSIONS

The Bara Shigri glacier is one of the second largest glaciers in the Himalayas. Numerous small size glaciers also join the main glacier region. Landsat data analysis clearly indicates that global warming has affected glaciers in Himalayan ecosystem. In this investigation, we have estimated the best method for glacier mapping is NDSI and also we estimate the loss of glacier area using NDSI value from 2002 to 2016. The investigation has shown an overall retreat in glacier area form 183.55sq. Km to 175.28sq. Km at 2002 to 2016. During the year of 1989 to 2002, the glacier snow cover area had increased by 6.52 sq. km, which can be due to the local climatological parameters. Between the year of 2002 and 2008, the area expanded by 14.35 sq. km (5.48%). Also, the snow cover area decreased by about 8.72 sq. Km, during 2008 to 2016. There was a maximum loss of snow cover area during this period of study. Therefore, a consistent decrease in overall snow covered area has been justifying using Landsat imagery of this region. Analyzed data clearly indicates that last 10 years (2008 – 2010) were the worst in the history of the Himalayan region in terms of glacier area loss. The WGMS data has also been used for correlation with NDSI, NDSI-2, NDGI, and Band ratio imagery to analyze the glacier area loss. Fig 6 shows Cumulative front variation and Annual thickness change of Bara Shigri Glacier for past years. The WGMS data has been used to identify and correlate in this research work. Following table shows comparison loss of Glacier area using different techniques from 1989 to 2016.

TABLE IV MEASURING THE AREA OF BARA SHIGRI GLACIER USING DIFFERENT METHOD

Year	NDSI (Area in sq. km)	NDSI-2 (Area in sq. km)	NDGI (Area in sq. km)	BAND RATIO (Area in sq. km)
1989	162.68	161.60	46.71	133.15
2002	169.20	166.62	97.77	121.16
2008	183.55	182.26	85.12	155.89
2016	175.28	173.54	72.33	127.09

The different methodology of glacier area measurement provides different accuracy. But the NDSI and NDSI 2 provides better accuracy than NDGI. NDSI and NDSI-2 method results are similar. Band ratio also shows a clear result of snow cover changes at Bara Shigri glacier. The estimated results of NDSI as follows 162.68 sq. Km in 1989, 169.20 sq. Km in 2002. 183.55 sq. Km in2008, 175.28sq. Km in 2016. Similarly, the NDSI – 2 gives results as follows, 161.60 sq. Km in 1989, 166.62 sq. Km in2002, 182.26 sq. Km in 2008, 173.54sq. Km in 2016. But NDGI gives a different result for estimating the area of bara Shigri as follows - 46.71 sq. Km in 1989, 97.77 sq. Km in 2002, 85.12 sq. Km in 2008, 72.33sq. Km in 2016. Band Ratio provides the snow cover area -133.15 sq. Km in 1989, 121.16 sq. Km in 2002, 155 sq. Km in 2008 and 127.24 sq. Km in 2016.

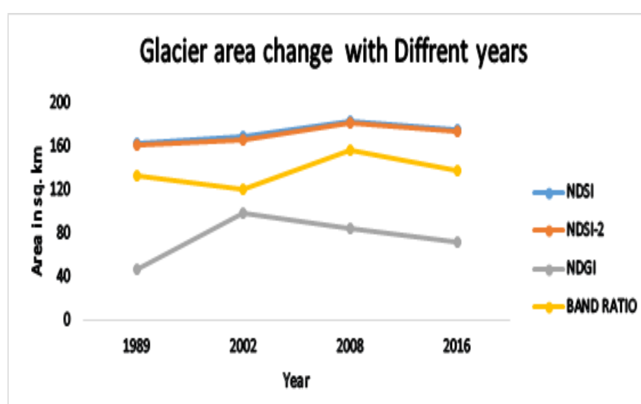

Fig.12 Glacier Area change

X. CONCLUSIONS

The present study confirms that Remote Sensing technique can be an effective way of monitoring glacier change and mass balance over this region. The present study clearly shows a decreasing trend in snow cover areas Bara Shigri region. In this region, the glacier reduces about 29 % because of the lower global temperature and balancing the earth's radiation.in the year of 2008 the early increase of snow cover area suggests an influence of snowfall in this region. Slow but gradual decreases of the snow cover area adverse effect of climate changes on the region are visible in the WGMS as well as in analyzed image data. This research also determines the best imagery for this research work of the two Landsat imagery, TM and ETM demonstrated the best detail the NDSI, NDSI-2, and Band ratio image. Image taken during the month of October ecause on the other month's images are useless; the winter winds obscure the surface. So, after we compare to a different method of glacial mapping the NDSI, NDSI -2 and band ratio is the best method of glacial mapping.

REFERENCES

[1] A.F.Hamlet and .P. Lettenmaier, "Effects Of Climate Change On Hydrology And Water Resources In The Colum ia River asin," *J. Am. Water Res. Assoc.,* Vol. 35, No.6, pp.1597-1623, 1999.

[2] Aparna Shukla, " igital Image Information Extraction Techniques For Snow Cover Mapping From Remote Sensing ata," *Encyclopedia of Snow, Ice and Glaciers*, pp.213-232, 2011.

[3] J. G. Corripio, "Snow surface al edo estimation using terrestrial photography," *International Journal of Remote Sensing*, Vol. 25, No. 24, pp. 5705–5729, 2004.

[4] DK Hall, JL Foster, JL. Chien and GA Riggs, " etermination of actual snow-covered area using Landsat TM and digital elevation model data in Glacier National Park, Montana," *Polar Record*, Vol. 31, No.177, pp.191-198, 1995

[5] A V Kulkarni, J Srinivasulu, S Manjul and Mathur, "Field ased spectral reflectance to develop N SI method for the snow cover," *J. Indian Soc. Remote Sens.*, Vol. 30, No.1 and 2, pp.73–80, 2002.

[6] A. K.Keshri, A. Shukla, and R.P. Gupta, "ASTER Ratio Indices For Supraglacial Terrain Mapping," *International Journal of Remote Sensing*, Vol. 30, No.2, pp. 519-524, 2009.

[7] J. ozier, "Spectral signature of alpine snow cover from the Landsat thematic mapper," *Remote Sensing of Environment*, Vol. 28, pp. 9–22. 1989

[8] Regine Hock, "Glacier Mass alance," *Summer School In Glaciology*, Fairbanks/McCarthy, pp. 7-17, 2010.

[9] M Anul Haq, Dr. Kamal Jain and r K.P.R. Menon, "Change Monitoring Of Gangotri Glacier Using Satellite Imagery," *12th Esri India User Conference*, pp.1-8, 2011.

[10] Jeyaram, Y.V.N. Krishna Murthy and .S. Srinivasan, "Mapping Of Bara Shigri Glacier, H. P. Using Digital Image Processing Techniques," *AARS*, session 1-2, 1994.