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Application of Remote Sensing and GIS in Monitoring of Glacial Mass Balance in Baspa Basin of Himachal Pradesh, India

Abstract

Glaciers and snow fields located in Himalayan mountain ranges are considered as a valuable national and global resource and form an important source of water into the North Indian Rivers. However, this source of water is not permanent as glacial dimensions change with climate. One of the important parameters to model future changes in glacial extent is the mass balance. Accurate estimation and proper monitoring of glacial mass balance is essential as it provides an insight of glacier-fed runoff pattern which is important for future water source management. In this study mass balance of three glaciers for hydrological years 2012 to 2015in Baspa basin (Kinnaur district, Himachal Pradesh) were estimated using remotely sensed data. Mass balance was calculated using Accumulation Area Ratio (AAR) method. Equilibrium line altitude (ELA) was estimated using Landsat 8 OLI surface reflectance product. Normalised Difference Principal Component Snow Index (NDPCSI) algorithm was used to generate multi-temporal mass balance data product. The result indicate a loss of 56.81 million cubic metre w.e. of glacial ice between 2012 and 2015. In addition, overall net mass balance in the hydrological year 2012–13, 2013-14 and 2014–15 was estimated as -12.34, -19.57 and -24.88 million cubic metre w.e., respectively for all the three glaciers.

Keywords: Glacier, Mass Balance, Accumulation Area Ratio, NDPCSI, Equilibrium Line Altitude.

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Introduction

Glaciers and snow fields located in Himalayan mountain ranges are considered as a valuable national and global resource and possess the largest concentration of frozen fresh water outside Polar Regions(SAC). In the Himalaya, glacier and snow-melt form an important source of water into the North Indian Rivers. However, this source of water is not permanent as glacial dimensions change with climate. One of the important parameters to model future changes in glacial extent is the mass balance(KULKARNI and ALEX). In this research work an attempt has been made to estimate the mass balance for 3 glaciers of Baspa basin, Himachal Pradesh using Accumulation Area Ratio (AAR) method with the help of remotely sensed data.

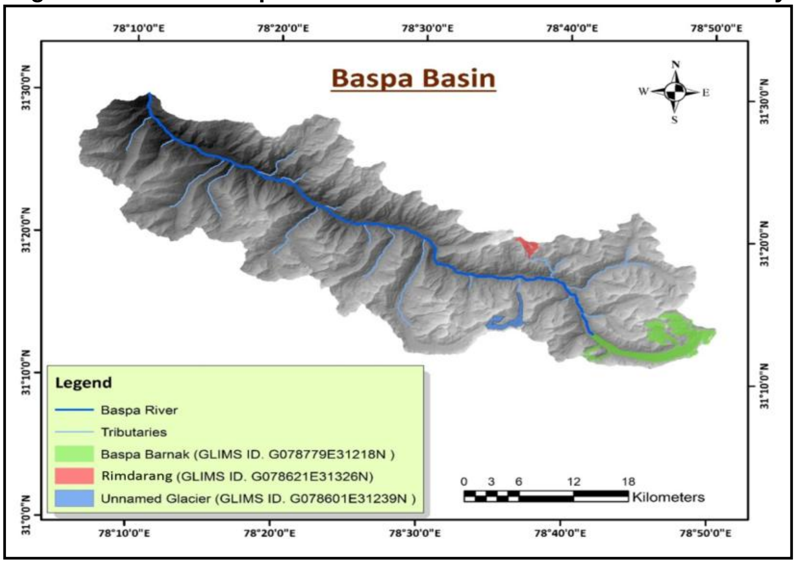
Aim of the Study

With respect to the ongoing debate and global concern about the scarce water resource and deteriorating health of the environment especially glaciers of the high mountains, there has been a need to adopt a scenario wise approach in the context of climate change. In view of the above, the proposed research has been undertaken with the objective to assess the actual state of glaciers in Baspa basin and to evaluate the sustainability of glaciers as an important resource of fresh water.The main aim of the study is to identify and demarcate the glacial boundaries and their terminuses and to find out the actual scenario of glacial mass balance in the region using remote sensing and GIS as a tool.

Study Area

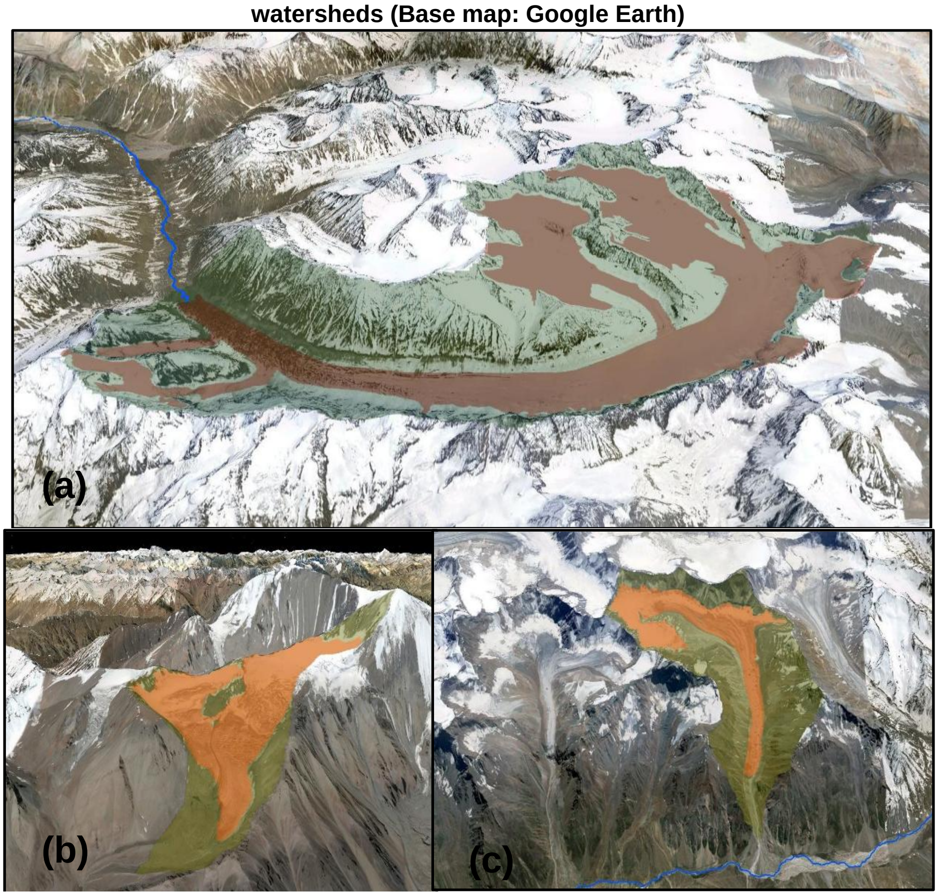
The study area comprises of three glaciers of BaspaRiver which is a part of Satluj basin and lies in wet zones of Himachal Pradesh in western Himalayas. The Bapsa basin lies between $31^0$10’01.00’’- $31^0$30’17.16’’ N lat. and $78^0$10’26.52’’- $78^0$52’41.75’’ E long. and is located in the south-east corner of Kinnaur district, HP.

Figure 1: Location map of Glaciers Selected for Mass Balance Study



One of three glaciers studied in this research work is Baspa glacier. Baspa glacier (DharVaspa/ GLIMSID.G078779E31218N/WGIID.IN5Q340 D0050) is compound valley type alpine glacier which extends over 31^{0}11'26''-31^{0}15'04'' N latitude and 78^{0}41'11''-78^{0}50'26'' E longitude. River Baspa originates from this glacier and this is the largest glacier of Baspa basin. The maximum length of the glacier along its centreline is 18.4 km from snout to upper accumulation zone.

Figure 2: (a) The Baspa glacier (GLIMS ID. G078779E31218N), (b) Rimdarang glacier (GLIMS ID. G078621E31326N) and (c) unnamed glacier (GLIMS ID. G078601E31239N) and their respective watersheds (Base map: Google Earth)



The other glacier is Rimdarang glacier (GLIMSID.G078621E31326N/WGIID.IN5Q340D0026) which is small valley type alpine glacier extends over $31^0$18'38''-$31^0$20'12'' N latitude and $78^0$36'23''-$78^0$38'07'' E longitude. The glacier is situated on the right side of the River Baspa. The maximum length of the glacier along its centreline is 4.2 km from snout to upper accumulation zone which covers mainly with ice, debris, snow and debris covered with ice. The present surface area of approximately 2.86 km2 of the glacier is unevenly distributed between 5107 and 6005 m a.s.l. with a mean elevation of 5573 m a.s.l. whereas the accumulation area has a mean elevation of 5817m (year 2015).

The third glacier is Unnamed glacier (GLIMS ID.G078601E31239N/WGIID. IN5Q340D0061) which is located in Dhuladhar Mountains at $31^0$13'40''-$31^0$16'18'' N latitude and $78^0$34'28''-$78^0$37'35'' E longitude and flows down valley to Baspa River. The glacier is composed of two parts partially separated by a huge medial moraine ridge. It occupies an area of 6.14 km2 and extends from 4640 m to 5750 m a.s.l. with a general exposure to the North. The mean elevation for the entire glacier is 5290 m whereas the mean elevation of the accumulation area is 5540 m a.s.l. in year 2015.

Review of Literature

In the Himalayas, first scientific glacial mass-balance study was carried out on Gara Glacier of Baspa basin from September 1974 (Raina and others, 1977) to 1983. After this Department of Science and Technology (Govt. of India) launched a coordinated programme on Himalayan glaciers in 1986 to conduct detailed mass balance studies as it is the key indicator of climate change as it is the direct, undelayed and un-filtered response to atmospheric climate change and hence is among the essential variables required for climate system monitoring. These studies were broadly based on the glaciological method (Raina, Kaul and Singh,1977; Srivastava and Swaroop, 1989; Sangewar et al.,1996 etc.) and estimated only short-term mass balance on a local scale only. Due to several inherent limitations of field-based methods, these studies were limited and fragmented in nature. Since the availability of repetitive remotely sensed data from high to medium resolution has increased and advancement in various GIS software has been taken place in the last two decades, application of remote sensing and GIS in the monitoring of glacial mass balance has increased manifold. A combination of various techniques is used in Geographical Information System (GIS) including manual, semi-automated and automated classification methods using remotely sensed satellite images, which include NDSI, Band Ratio, NDPCSI, Land Surface Temperature and Backscatter Coefficients to determine accumulation, ablation and ELA of a particular glacier (Kulkarni et al., 2005; Negi et al., 2009; Crawford, Manson, Bauer, & Hall, 2013; Basnett, Kulkarni, &Bolch, 2013; Kumar & Kumar, 2016). These studies reveal that most of the glaciers of the region experienced a negative glacier-wide mass balance with varying rate.

Material and Methodology

Dataset Used

The mass balance of glaciers is not homogenous in space and time. To study such changes there is need to generate a time series of various glacier parameters by using satellite imageries for different time period of the region. The main criteria needed to be fulfilled while selecting the imageries under this mass balance study is that the images should be cloud free (keeping additional criteria as cloud cover below 10%) and acquisition date should be correlate with end of ablation season. Landsat 8 OLI sensor having high spatial and radiometric resolution was chosen to map and extract various parameters of glaciers. Components of mass balance are not directly measured from space borne satellite but the parameters used to evaluate mass balance can be estimated. Mainly two different remotely sensed data used to carry out the necessary study.

Landsat 8 OLI Imagery

In total 3 imageries of Landsat 8 OLI sensor was selected for this mass balance study. The required imageries were downloaded in L1T data type and GeoTiff format from USGS's Earth Explorer Website **(http://earthexplorer. usgs.gov)**.

Table 1: List of Satellite images used for mass balance estimation and their specifications

	Landsat Scene Identifier	WRS Path/Row	Sensor Identifier	Date Acquired	Image Quality	Scene Cloud Cover
1	LC81460382015251LGN00	146/038	OLI_TIRS	08/09/2015	9	6.05
2	LC81460382014264LGN00	146/038	OLI_TIRS	21/09/2014	9	5.67
3	LC81460382013261LGN00	146/038	OLI_TIRS	18/09/2013	9	5.91

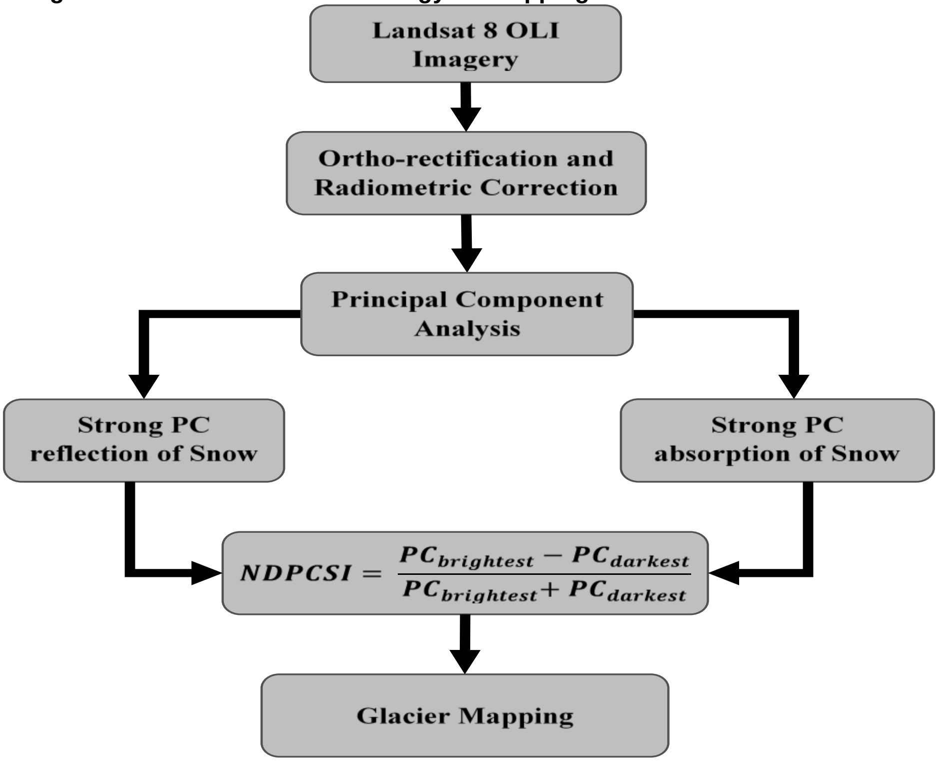
Aster GDEM (V 2.0) DEM

Aster GDEM V 2.0 image of the region is downloaded from USGS Earth Explorer website in GeoTiff format with geographic lat/long coordinates and a 1 arc second (≅30 m) grid of elevation postings. It is referenced to the WGS84 geoid. It was used to delineate glaciers watershed and to add elevation information to different parameters of glaciers.

Methodology

The mass balance is calculated using the Accumulation Area Ratio (AAR) method (KULKARNI and ALEX), which gives the balance for the hydrological year i.e. between two successive ends of ablation season surfaces. In AAR method accumulation area of a particular glacier is demarcated to calculate mass balance. To differentiate between accumulation and ablation areas and to estimate Equilibrium Line Altitude (ELA) a new technique that combines the principal component imagery generated using PCA with commonly used NDSI, referred to as Normalised Difference Principal Component Snow Index (NDPCSI) is used(Sibandze, Mhangara and Odindi). NDPCSI has a better classification accuracy over traditional NDSI. The superiority of the NDPCSI can particularly be attributed to the ability of principal component analysis to de-correlate snow from water bodies and shadows.

Figure 3: Flow Chart of Methodology for Mapping of Various Zones of Glacier



Following steps have been carried out for mass balance study:

1. Delineation of glaciers watershed boundary using Arc Hydrology Tool with the help of ASTER GDEM.
2. Image pre-processing (a) Ortho-rectification: Geocoded image in WGS84, UTM Zone no 44 (b) Radiometric Correction:-Conversion of DN value to reflectance.
3. Delineation of glaciers boundary: Band ratio, semi-automated technique along with manual delineation is used to differentiate glaciers and other terrain and mask water bodies, shadows, bare rocks etc.
4. Mapping of various zones of glacier: NDPCSI index is calculated to do zonation of glacier. Mapping of accumulation and ablation zones of glaciers by applying suitable threshold to NDPCSI and calculation of accumulation area and total area of glacier.
5. Calculation of AAR for each dataset.
6. Establishing the linear relationship between specific mass balance and area accumulation Ratio and estimating the specific mass balance.
7. Calculation of net mass balance and net mass gain/loss.

Figure 4: Principal components 1 to 8 for Landsat 8 OLI scene ID LC81460382015251LGN00 dated 08-sept-2015. PC1 and PC2 show highest snow reflectance and absorption respectively

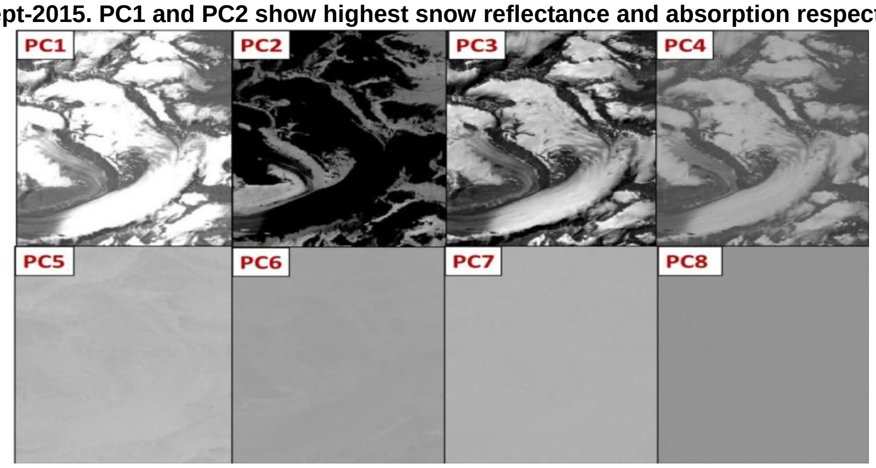
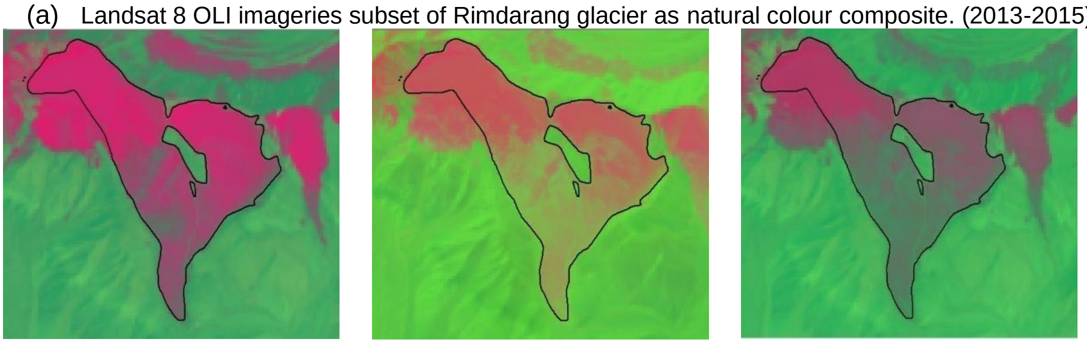


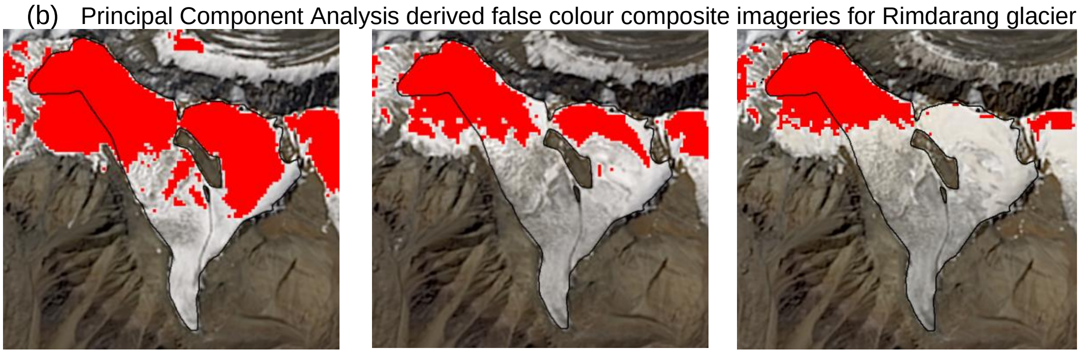
Figure 5: Different steps followed during Mass Balance study

LC81460382013261LGN00 Date acquired: 18/09/2013 | LC81460382014264LGN00 Date acquired: 21/09/2014 | LC81460382015251LGN00 Date acquired: 08/09/2015

(a) Landsat 8 OLI imageries subset of Rimdarang glacier as natural colour composite. (2013-2015)



(b) Principal Component Analysis derived false colour composite imageries for Rimdarang glacier



(c) Accumulation area of Rimdarang glacier derived from NDPCSI. Only NDPCSI value ≥ 0.45 is applied as a threshold value.

Results and Discussions

Estimation of glacier mass balance is a challenging task as it requires a lot of field work. But with the advancement in the field of remote sensing and Image processing it becomes feasible to apply semi-automatic techniques and algorithms on satellites data and derive some parameters through which mass balance can be estimated. Table 2 provides the detailed results obtained through the analysis of NDPCSI from this study. A brief account of these results is discussed in the following paragraphs.

Table 2: Specific mass balance for selected glaciers in Baspa Basin, Himachal Pradesh

	Glacier Name	GLIMS ID	Glacier Area (km^2)	Mean Elevation (m a.s.l.)	Snowline Altitude (m a.s.l.)	Accumulation Area (km^2)	AAR	Specific Mass Balance (cm w.e.)
Hydrological Year 2012-2013								
1	BaspaBarnak	G078779E31218N	33.14	5150	5361	10.87	0.33	**-41.162**
2	Rim Darang	G078621E31326N	2.86	5573	5491	1.89	0.66	**39.720**
3	Unnamed	G078601E31239N	6.14	5540	5310	3.12	0.50	**2.613**
Hydrological Year 2013-2014								
1	BaspaBarnak	G078779E31218N	33.14	5150	5385	9.20	0.28	**-53.407**
2	Rim darang	G078621E31326N	2.86	5573	5646	1.07	0.37	**-29.953**
3	Unnamed	G078601E31239N	6.14	5540	5400	2.63	0.43	**-16.779**
Hydrological Year 2014-2015								
1	BaspaBarnak	G078779E31218N	33.14	5150	5460	7.8	0.23	**-63.674**
2	Rim darang	G078621E31326N	2.86	5573	5708	0.69	0.24	**-62.242**
3	Unnamed	G078601E31239N	6.14	5540	5460	2.23	0.36	**-32.611**

(Mass balance values are in water equivalent)

During the study, AAR and specific mass balance were estimated for each individual glacier. The results show that for BaspaBamak glacier, the specific mass balance values remain negative for all the three years. In year 2012-13 the value was -41.162 cm w.e. which decreased further for year 2013-14 and 2014-15 to -53.407 cm w.e. and -63.674 cm w.e. respectively.

For Rimdarang glacier which is a small glacier situated in south facing slopes of basin, the specific mass balance value was positive for the year 2012-13 and the value was quite high i.e. +39.720. This gives an impression that in year 2012-13 the glacier gained more snow during accumulation season in comparison to the loss during ablation season. But for the next successive years 2013-14, 2014-15; the results show different scenario. The glacier experienced negative specific mass balance (-29.953 and -62.242 cm w.e. respectively) for these years.

For Unnamed glacier which is medium sized glacier, the specific mass balance value was slightly positive (+2.613) for the year 2012-13 but for the remaining two years the values were negative (-16.779 and -32.611 for the year 2013-14 and 2014-15 respectively).

During the studied period, all the three glaciers experienced upward shift of ELA. For BaspaBamak, the shift was 99 m and for the Rimdarang and unnamed glacier this upward shift was reported as 217 m and 150 m respectively for the complete duration of three year.

For each glacier, specific mass balance values were multiplied by its total glacial area to obtain net mass balance.

Table 3: Net mass balance, in million cubic metre water equivalent, estimated for selected glaciers of Baspa basin from 2012-13 to 2014-15

Year	Net Mass Balance (In million cubic metre w.e.)			Total
	Glacier			
	BaspaBamak	Rimdarang	Unnamed	
2012-13	-13.64	1.13	0.16	-12.35
2013-14	-17.69	-0.85	-1.03	-19.57
2014-15	-21.1	-1.78	-2.00	-24.88
Total	-52.43	-1.5	-2.87	-56.8

The mass balance of each glacier was added to assess total loss/ gain of glacial ice in 3 years. The investigations suggest a loss of 56.81 million cubic metre w.e. of glacial ice between 2013 and 2015. In addition, overall net mass balance in the hydrological year 2012–13, 2013-14 and 2014–15 was estimated as -12.34, -19.57 and -24.88 million cubic metre w.e., respectively.

The investigation has shown that all glaciers have negative mass balance and loose more snow and ice due to melting than accumulation of seasonal snow except in year 2012-13 when unusual high snowfall (recorded highest after 1997) induced positive mass balance in two small glaciers. This loss in glacial ice will have profound influence on glacial extent too.

The Rimdarang glacier has shown more fluctuation in specific mass balance values i.e. +39.72 to -62.24 (change of 101.96 point) than other two glaciers- BaspaBamak and unnamed which have change of 22.51 and 35.22 points respectively over the entire period of study. The reason is small size and comparatively debris free surface of Rimdarang glacier make it more sensitive to climate change.

Conclusions

These results give insights into the mass-balance trend of the glaciers of the basin over the last three years. The basin experienced overall negative net mass balance over the period revealing strong unsteady-state conditions of the glaciers of the basin. Again, the analysis reveals that glaciers with extensive debris cover, have a qualitative difference in their response to change in climate as compared to bare ones. The study also reveals that various glacier parameters like areal extension, location, debris cover, shape, slope gradient etc. influence the behaviour of the glacier and manipulate the response time of the glacier regarding climate change.

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