Seasonal and Temporal Dynamics of Snowline Altitude in the Baspa Basin of Himachal Pradesh

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Abstract: Snow and its melt dominate regional climate and hydrology in Himalayas. Accurate estimation of seasonal and temporal dynamics of snowline elevation is essential as it provides an insight of snow cover and snowmelt-induced runoff pattern which is important for future water resource management. In this study spatio-temporal variations of snowline for past two decade from 1994 to 2014 in Baspa basin located in the Kinnaur District, Himachal Pradesh are reported. Snow cover extent was estimated using Landsat surface reflectance product. Normalized Difference Snow Index (NDSI) algorithm was used to generate multi-temporal time series snow cover and snowline data product. The results indicate large variation in snowline elevation pattern and ascending trend. The results depict that in 1994, the average peak ablation period snowline elevation of the whole Baspa watershed was 5231 meters above the mean sea level and it was ascended to 5298 meters in year 2014. The total shifting of peak ablation snowline was observed about 67 meters during last 20 years i.e. from 1994 to 2014, at the rate of 3.35 m/year. The lowest average peak ablation period snowline altitude was observed as 5194 m asl in sept-1997 and highest as 5298 m asl in sept-2014.

1. Introduction

Snow is a common global meteorological phenomenon known to be a critical component of the hydrological cycle. Snow and its melt dominate regional climate and hydrology in many of the world's mountainous regions. One-sixth of Earth's population depends on snow or glacier melt for water resources [1]. Snow is one of the most important land cover type in the Himalaya too, which act as an important source of fresh water for many north Indian rivers [2]. Accurate estimation of seasonal and temporal dynamics of snowline elevation is essential as it provides an insight of snow cover and snowmelt-induced runoff pattern which is important for future water resource management [3]. Snow cover also plays an important role in the climate system by affecting energy exchange and mass transfer between the atmosphere and the surface and developing weather and climate, both locally and regionally. In addition, the snow cover itself is a surface condition that affects the Earth’s radiation balance [4] and is an important element in meteorological and climatological modelling tools [5]. The spatial and temporal distribution of snow cover also represents an important climate record of use to hydrologists, climatologists, ecologists, and other scientists and resource managers. Detailed information regarding snow distribution can be relevant input in hydropower generation system, water management, tourism, agricultural land use, forestry, civil engineering, river fisheries, fresh water supply for consumptive use, strategic planning and many other developmental activities in any region. It can enhance local and regional management approaches.

Snow pack is also considered one of the most destructive natural hazards as it causes avalanches every year in mountainous regions including Himalayas. As a result, information regarding snow cover may contribute to natural hazard management and protection [6]. Snow cover is also associated with other geohazards in high mountain regions. The rate of snow cover disintegration affect the availability of water as a lubricant for various geohazards such as landslide, rock fall, mudflow etc. The snowline is a line on the earth surface intersected by a hypothetical surface on which ablation of snow and ice is balanced with snowfall at a given point of time. The snowline is an important indicator of snow coverage. A periodical study of the spatial-temporal variations of the snowline can help in assessing the hydrologic cycle balance as well as to understand the regional and global climatic changes.

2. Study Area

The study area comprises of glaciated basin of Baspa river which is a part of Satluj basin and lies in wet zones of Himachal Pradesh in western Himalayas. The Baspa basin lies between 31°10’01.00”–31°30’17.16”N lat. and 78°10’26.52”–78°52’41.75”E long. and is located in the southeast corner of Kinnaur District, HP. It occupies an area of 1100 sq. km, with elevation ranging from 1770 to 6465 m asl. The Baspa river which rises near the
Indo-Tibetan border, flows through Kinnaur, forming famous Baspa valley (it also known as Sangla valley) from Chitkul (3475 m) to the point of confluence with the Sutlej river i.e. at Karchham (1770 m asl). The Baspa River is a fifth order drainage basin which originates from Baspa-Bamak glacier. The Melting snow and ice are major contributors to the river. A large part of this 75 km long valley is either arable land or covered with forest. The Baspa Valley is characterized by lofty snow peaks, with around 35 important north and south-facing glaciers which cover an aerial extent of 167 km. The glaciers include valley glaciers and small permanent snow/ice fields. These glaciers exhibit erosional and depositional geomorphic features, which indicate post glacial activity in the valley.

Figure 1. Location map of Baspa Basin, Kinnaur District, Himachal Pradesh.

The left bank tributaries of Baspa are Karu, Shanchay, Jorya Garang, Janpa Garang, Nardu Garang, Shaune Garang, Hurba Khad, Rokti Khad, Shaung Khad and Baura Khad. The streams joining Baspa on its right bank are smaller compared to the left bank streams. Some important tributary streams on the right bank are: Tumar, Rimdarang, Shilpya, Shushang, Mangsa and Gor Garang. Geomorphologically, the whole basin has been subdivided into fluvial terrain, fluvio-glacial terrain, alpines/meadows and rocky terrain.

Figure 2. Relief map of Baspa basin showing increasing trend in elevations from west to east.

3. Materials and Methodology
Obtaining snow cover information on repetitive basis from vast snow covered areas of Himalaya using conventional snow courses and mapping techniques are very difficult due to high altitude, inaccessible and rugged mountain terrain and it only provide the point measurements of snow.

Alternatively, remote sensing offers a new and valuable tool for obtaining snow data. In the recent years, this technique has emerged as a popular viable substitute for real-time, year-round and large spatial coverage for monitoring and process studies over vast, rugged and remote areas [7, 8].

In this research work, a methodology based on the NDSI index obtained from radiometrically corrected images with a threshold > 0.4 is used to determine snow cover over a large and heterogeneous area of Baspa basin by means of remotely sense data of Landsat-8 OLI (Operational Land Imager), Landsat 7 ETM+ and Landsat 5 TM Surface Reflectance product images.

A set of 10 Landsat 8 OLI Surface Reflectance product images of path 146 and rows 38 downloaded from Earth Explorer of USGS for Sept-2014 to May-2015 have been chosen to perform seasonal snow cover study. For temporal snow cover study a set of 6 images of surface reflectance product of Landsat 8 OLI, Landsat 7 ETM+ and Landsat 5 TM, related to peak ablation period of the concerned year has been used. Cloud-free images have been selected to cover all months of the year to take into account different seasonal situations.

The methodology used in this research work for determining the snow cover area and dynamics of snowline of study area is described in the following steps:

- Preparation of base map by delineation of Baspa river watershed boundary using Arc Hydro Tools with the help of ASTER GDEM v 2.0.
- Image pre-processing (a) Ortho-rectification (b) Radiometric Calibration.
Table 1. List of Satellite images used for seasonal and temporal snowline estimation and their specifications.

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4. Results and Discussions

4.1 Seasonal Snowline

In order to analyze snowline and their seasonal and temporal dynamics, elevation information is added to snowlines by using Aster GDEM. The snowline elevation through hydrological year resulted in what we expected from literature studies:

- Computation of various Spectral Indices (NDVI, NDWI etc.) and Masks (masks for vegetation, cloud, water body, shadows, rocks etc.)
- Computation of NDSI using Green and SWIR band of Landsat Images.
- Creation of seasonal and temporal snow cover product by applying suitable threshold values.
- Delineation of seasonal and temporal snowlines using semi-automated technique and adding surface information to them using Aster GDEM.
a much lower snowline in the winter months than in the summer. This is because of the fresh snowfall in winter, November till April, and the melting of snow in summer, May till October.

Figure 6. Seasonal snowline variation pattern in Baspa basin for hydrological year 2014-2015.

In hydrological year 2014-2015 for the month February, the average snowline was much lower than all the other months and descended to 3400 m a.s.l. From September to mid-November the snowline remained constant with marginal descend as it was peak ablation season with minimal snow cover and whatever snow the region got in last accumulation period was already melted out during early ablation period i.e. May to August.

Figure 7. Seasonal snowline variation pattern in Baspa basin for hydrological year 2014-2015.

From mid-November onwards snowline has shown sharp decline due to first spell of winter snowfall. Up to December end the snowline descended to 3761 m a.s.l. from 5200 m a.s.l. The difference between average snowline elevations of mid-December 2014 to February 2015 was marginal and up to March the snowline elevation was remain almost the same, probably due to the various spell of fresh snowfall in the basin.

4.2 Temporal Snowline

The results depict that in 1994, the average peak ablation period snowline elevation of the whole Baspa watershed was 5231 meters above the mean sea level and in year 2014 it was shifted to 5298 meters. This upward shift is due to decrease in snow cover area as in September 1994 the total snow cover area is estimate 238 km2 which reduced to 194 km2 in September 2014.

Figure 8. Temporal snowline variation pattern in Baspa basin from hydrological year 1993-94 to 2014-15.

Hence, the total shifting of snowline was observed about 67 meters during last 20 years i.e. from 1994 to 2014, at the rate of 3.35 m/year. The lowest average peak ablation period snowline altitude was observed as 5194 m a.s.l. in sept-1997 and highest as 5298 m in sept-2014.

5. Conclusions

Remote sensing based dataset and their final product by using GIS (e.g. Binary snow cover map, snowlines map etc.) have high capability in snowline mapping and can provide insight on snowline dynamics of the region and can be used for climatological assessment of snow conditions in vast areas.

For the identification of snow the Normalized Difference Snow Index (NDSI) proved its usability. Especially for large datasets it is easy to apply in an automated process. It is providing reliable information at regional scale and is easily applicable.

The snowline product can be used together with a DEM. This combination provides additional capability to analyze the impact of local topography on snowline.

Satellite-based Snow cover product can provide information about spatio-temporal dynamics of the snow cover and snowlines which can provide important parameters for climate trend analysis, forecasting of hydrological extremes (drought and flood), and water resource management.
It is evident from this study that during the time period of 20 years (from 1994 to 2014), the snow cover area is depleting in the Baspa basin which makes the watershed more vulnerable to various geohazards such as avalanches, landslide, rockfall etc. thus based on the snow cover and snowline products environmental changes can be documented.

For small catchments like Baspa basin, Landsat images proved its suitability because of higher spatial resolution and moderate temporal resolution and can be used for both temporal and seasonal change detection.

References


