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Impact of change in Himalayan snow covered area on discharge of river Brahmaputra

Swapnali Barman and RK Bhattacharjya

Indian Institute of Technology, Guwahati, Assam, Guwahati- 781039, India

Corresponding *e*-mail: swapnali.barman@gmail.com and rkbc@iitg.ernet.in

Abstract

Himalaya is the largest body of glaciers outside the Polar Regions. Due to the Global Warming, glaciers in many parts of this region have undergone significant retreat which in turn leads to increase in discharge of the Himalayan Rivers. In this paper, an attempt has been made to study how the snow covered area of the Brahmaputra River Basin changes the discharge of the River Brahmaputra. For this, MODIS image MOD09A1.5 (MODIS/Terra Surface Reflectance 8-Day L3 Global 500m SIN Grid) of 500m resolution consisting of seven bands has been taken to prepare the Normalized Difference Snow Index Maps. The NDSI map is then used to obtain the areal extent of snow in the Himalayan region. The NDSI maps are prepared starting from 2002 to 2012 at three months interval, i.e. January, April, July and October. To study its effect on discharge, discharge data of the Pandu Gauge Site for the Brahmaputra River has been taken starting from 2002 to 2012.

INTRODUCTION

Himalaya is the largest body of glaciers outside the polar region. Himalayan are also covered by seasonal snowfall during of snow cover changes significantly during winter and winter time, which starts ablating in spring, therefore areal extent spring [1]. Impacts of the shrinkage and disappearance of mountain glaciers include changes in the flow characteristics of glacier-fed rivers. The major river systems of the Indian subcontinent, Brahmaputra, Ganga and Indus, which originate in the Himalayas are expected to be much vulnerable to climate change because of substantial contribution from snow and glaciers [2,3].

Due to the large extent and difficult accessibility of high mountainous terrain, remote-sensing techniques provide an efficient way to collect data in such regions. Identification of snow cover using only the visible reflected light may be difficult because many things appear as white, such as clouds or even rocks. MODIS imageries have successfully been applied in monitoring snow cover from space using the Normalize Difference Snow Index (NDSI).

Study of both Snow Covered Area and depth of snow are important to understand the changes in discharge of a river. But, here in this study, we restrict our analyses only to the determination of the changes in snow covered area of the Himalaya that covers the Brahmaputra river basin.

The Brahmaputra River Basin that lies between the coordinates 23.9˚N to 31.5˚N Latitude and 82.1˚E to 97.7˚E longitude with drainage area of 580,000 sq.km. is considered in this study.

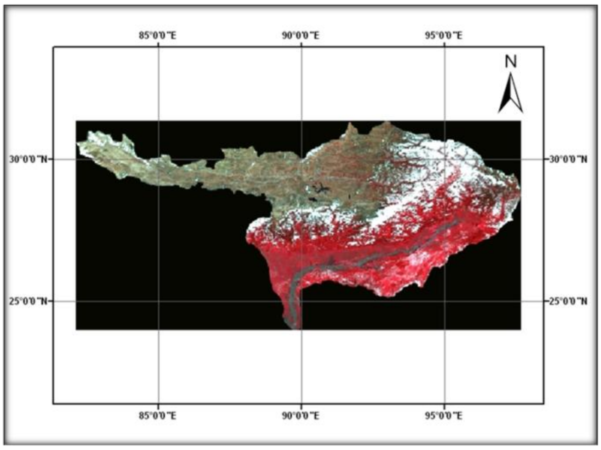

Fig. 1. FCC image of the Brahmaputra River basin prepared from the MODIS image.

MATERIALS AND METHODS

A. Data used

The variation in snow covered area in the Himalayan range is studied starting from 2002 to 2012 for the months of January, April, July and October using the MODIS image, MOD09A1.5 (MODIS/Terra Surface Reflectance 8-Day L3 Global 500m SIN Grid)of 500m resolution consisting of seven bands (band1 to band7) . The discharge data at Pandu gauge site has been taken to study the effect of snow/glacier change on discharge.

B. Normalized difference snow index (NDSI)

NDSI method is generally used for snow cover mapping using satellite data [4-6]. NDSI uses the high and low reflectance of snow in visible (Green) and shortwave infrared (SWIR) region respectively. Additionally, the reflectance of clouds remains high in SWIR band, thus NDSI allows in discriminating snow and clouds. NDSI ranges from -1 to +1 and is defined by the following relation:

$$NDSI = \frac{Green - SWIR}{Green + SWIR}$$

Where, Green and SWIR are the reflectance of the green and shortwave infrared bands respectively. Snow has a high reflectance in band4 (0.545-0.565µm, visible green) and a low reflectance in band6 (1.628-1.652µm, shortwave near infrared) of the MODIS instrument. A threshold value of NDSI of 0.4 is defined for the pixels that are approximately 50% or greater covered by snow from imageries of different sensors [7]. Distinguishing snow from other non-snow features such as water, or dense forests may be difficult because they have similar NDSI readings to snow. Therefore, it is necessary to examine other wavelengths to distinguish these features from snow cover. Hence, reflectance in band 2 and band 4 are examined to separate water bodies and forest respectively from snow. Again the NDVI is also examined to mark a pixel as snow covered forest. NDVI is defined by the following relation:

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

Where, VIS and NIR stand for spectral reflectance measurement acquired in the visible (red) and near-infrared regions respectively.

C. Preparation of snow map

There are a total of five tiles that cover up the complete study area. All those tiles were then mosaiced and subset in Erdas Imagine software to get the required study area.

After getting the study area, the Normalized Difference Snow Index (NDSI) map for each image was prepared. Snow is highly reflective in the visible part of the EM spectrum while highly absorptive in the short wave infrared part of the EM spectrum. A normal false color composite image does not distinguish between the snow and clouds as both features have high and same spectral reflectance in visible to NIR region of electromagnetic energy. This problem is solved by using the middle infrared (MIR) portion of electromagnetic energy. Snow has strong absorption band near 1.44 to 1.52 µm which results in near zero reflectance for snow, whereas clouds have higher reflectance in this region of EM energy. Therefore, NDSI, which uses the MIR portion of electromagnetic energy can efficiently differentiate between snow and cloud cover of a satellite image. Again, if NDSI > 0.4, then the pixel is snow, else not snow). For separating water bodies from snow, if the pixels with reflectance in band 2 (0.841- 0.876 µm) is less than

11% even if the NDSI is greater than or equal to 0.4, were mapped as water. Similarly, for a pixel where the NDSI is greater than or equal to 0.4, but the reflectance in band 4 (0.545-0.565 μm) is less than 10% has been marked as dark forest.The reflectance from the forest areas that consist of dense conifers to less dense deciduous forests will be considerably darker than non-forested areas even with substantial depths of snow. The challenge is to determine the snow-covered areas when they may not be directly detectable. If a pixel NDSI value is less than 0.4 (not snow) but the NDVI is approximately 0.1, the pixel could be snow-covered forest [5]. These measures prevent low reflective features like water bodies and dense forest canopies from being misclassified as snow.

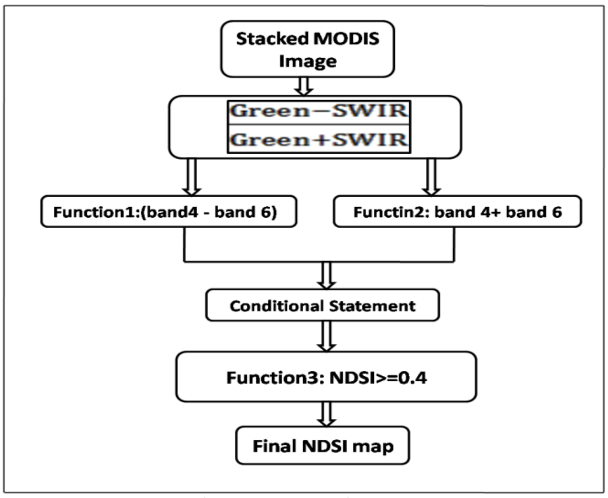

Fig. 2. Flowchart for preparation of NDSI in Erdas Imagine.

The flowchart above (Fig. 2) gives an overall understanding of the steps to prepare NDSI in the model maker tool of the Erdas Imagine software. For the original input image, two functions were performed to make the numerator and denominator of the NDSI equation. The data also needs to have 100 added to eliminate negative values and also scaled by a factor of 10^4. If band 4 + band 6=0 (the denominator), the NDSI was not performed as NDSI value will be infinity. Also, a data value of -28672 was ignored. Again, another function in the model maker was created which considers the pixels having NDSI values of greater than or equal to 0.4 as snow. Applying this model to all the required images, NDSI images were created from 2002 to 2012 for the moths of January, April, July and August. All pixels with a reflectance of less than 11% in band 2 are water and were eliminated. Forest can be identified by examining band 4. All pixels with a reflectance of less than 10% in band 4 are forest and were eliminated accordingly. To identify the snow covered forests, the NDVI (Normalized Difference Vegetation Index) was examined. If the NDVI is about 0.1, a forest pixel was mapped as snow even if the NDSI was less than 0.4 (Fig.3).

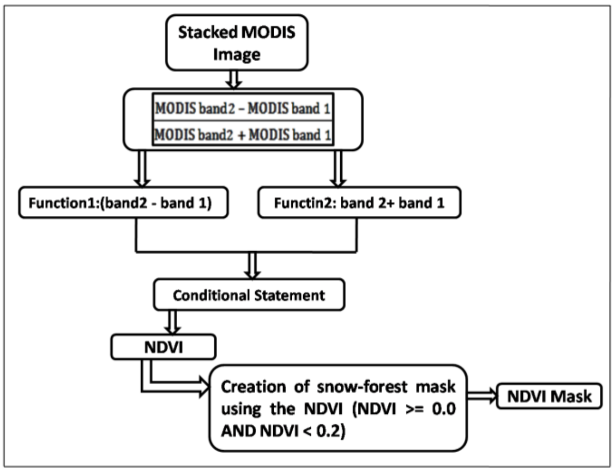

Fig. 3. Flowchart for NDVI mask prepared in Erdas Imagine

MODIS bands 2 (NIR) and band1 (Red) are used to create NDVI. In the NDVI model, the following function was added to create snow forest mask:

$$NDVI \geq 0.0 \quad \text{and} \quad NDVI < 0.2$$

The created water, forest and NDVI masks are applied to the NDSI product to get the final snow map from which the area covered by snow/ glacier can be determined. The values within the NDSI, water, forest and NDVI masks are 1 if true (snow pixel) or 0 if false (non snow pixel).

RESULTS AND DISCUSSION

The snow maps for January, April, July and October of 2002 to 2012 are prepared in the Erdas Imagine software using the methodology presented above. Fig.4 shows the image created using the presented methodology. In the image, the white pixels show the snow covered area while black pixels show the non-snow area.

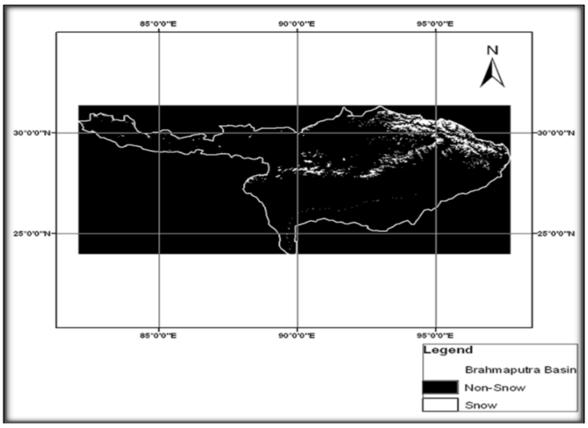

Fig. 4. Final map showing snow covered area

The increasing and decreasing trend of discharge at Pandu with respect to the change in snow/glacier covered area of the study area for all the four months from 2002 to 2012 are shown in Fig.5 (a,b, c and d).

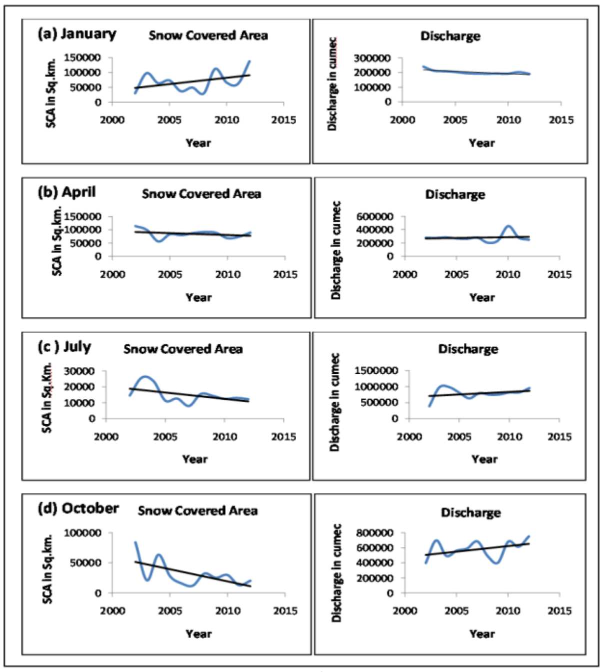

Fig. 5. Trend showing Variation of discharge w.r.t snow covered area for the month of (a) January, (b) April, (c) July and (d) October from 2002 to 2012.

While building a relationship between the snow covered area and discharge data, it has been found that for the month of January, the discharge is in a decreasing trend with respect to the increasing trend of snow covered area for the same period. The minimum snow cover during this period was in the year

2008 with a value of 29822 square kilometer and the maximum was in the year 2012 with a value of 138555 square kilometer. While the minimum discharge was in the year 2008 (193621.97 cumec) and maximum was in the year 2002 (242363.27cumec).

For the other three months *i.e.* April, July and October, the results plotted in graphs (Fig.5 (b), (c) and (d) show a positive correlation between decrease in snow covered area and increase in discharge. This reduction in snow cover may be due to the impact of climate change. This gradual melting of snow due to the raise in temperature is affecting the downstream hydrology of the Brahmaputra River basin, causing severe flood in the monsoon season as well as riverbank erosion at some vulnerable points which is definitely a threat to the development of the entire region. An increased seasonal melt coupled with rains will bring more intense floods to the downstream areas. Impacts of the shrinkage and disappearance of mountain glaciers include changes in the flow characteristics of glacier fed rivers; glacier lake outburst floods (GLOFs) and changing flood severity and frequency. The GLOFs are capable of releasing billions of cubic meter of glacier water, stored for decades without warning to those living downstream. For the month of April, minimum snow cover was observed in the year 2004 (56236 square kilometer) and maximum was observed in the year 2002 (114588 square kilometer). Similarly for the month of July minimum snow cover was observed in the year 2007 (7881 square kilometer) while the maximum was observed in the year 2003 (25851 sq.km.). For the month of October, the minimum was observed in the year 2007 (12347 square kilometer) and the maximum was observed in the year 2002 (84551 square kilometer). In case of discharge, the minimum in the month of April was observed in the year 2008(206278.20 cumec) and maximum was observed in the year 2010 (457200.00cumec). For the month of July, minimum was observed in the year 2002 (383687.00cumec) and maximum was observed in the year 2012 (954472.95cumec). On the other hand, for the month of October, the minimum discharge was observed in the year 2002(399539.40cumec) and maximum was observed in the year 2012 (754642.92cmec). Melting of snow/glacier with respect to the rise in temperature has a major impact on the hydrology of the rivers originating from these glaciers. Brahmaputra, the major river of the study area, is responsible for many natural calamities among which flood and erosion are the severe ones. Along with the heavy rainfall of this region, the melting of snow/glacier at the origin of the river also has a major effect on change in its discharge. In mountain region particularly, global mean temperature has not been spatially homogeneous. A minor variation in temperature under low magnitude warming is more effective to changes in volume and area of glacier than high magnitude warming.

CONCLUSION

From this study, it has seen that MODIS data are useful in mapping snow cover of large areas like the Himalayas, because of its good spatial as well as temporal resolution. Since snow reflects more energy in the visible part than in the mid-infrared, the NDSI ratio enhances the contrast between snow and bare ground. Additionally, the reflectance of clouds remains high in MODIS band 6. Thus, the NDSI allows us to discriminate clouds and snow. In this study, an attempt has been made to correlate change in discharge of the river Brahmaputra with the change in snow/glacier cover. It is seen that except for the month of January, the snow covered area for other three months *i.e.* April, July and October showing an increasing trend with decrease in snow covered area. This melting of glaciers has a huge potential of causing damage at the downstream of the river.

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