SNOW COVER MAPPING FOR SUSTAINABLE WATER RESOURCE MANAGEMENT IN THE BALKHAB RIVER BASIN IN AFGHANISTAN USING MODIS SATTELLITE NORMALIZED DIFFERENCE SNOW INDEX (NDSI) PRODUCTS

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ABSTRACT

Snow cover and mountain glacier are the main source of water in Afghanistan. In this study, the MODIS NDSI snow cover C6 were used for the snow cover mapping over Balkhab River basin in the Northern river basin, Afghanistan. Average cloud coverages in the MODIS Aqua and Terra images were high with 37.6% and 31.8%, respectively, from 1st January 2010 to 31st December 2018, and then were improved by spatial and temporal combinations; Aqua and Terra combination (A/T), Temporal combination of (A/T) products with preceding (A/T +1day) and previous days (A/T -1day). The 3 steps combination reduced the average cloud coverage down to 8.9%. Validation and confirming the accuracy of remote sensing data is important. Since historical observed data is not available for the study area, the Landsat 8 images with less than 20% cloud cover for the months with higher snow cover were chosen for the validation. In addition to the direct pixel-by-pixel comparisons, confusion matrix is utilized for validation. A confusion matrix is a summary of prediction results on a classification problem to describe the performance of a classification model. In direct comparison, 86.47% of the pixels are matching. In the confusion matrix, the overall accuracy (ACC) is increased to 89.37% because the cloud pixels are also land or snow in real. The MODIS final product of this study can be used for assessment of the contribution of snow-melt water to the river stream, and the effect of climate change on the amount of snow accumulation during study period.

Keywords: snow cover extent, MODIS, water resource management, confusion matrix, sustainability

1. INTRODUCTION

Annual snow cover extent (SCE) over Northern Hemisphere land surface averaged 25.6 million km^2 in 2018 (Robinson & Robinson, 2018). The Moderate Resolution Image Spectroradiometer (MODIS) snow cover extent products serve as a reliable source of snow measurements for hydrologic studies as well as for data assimilation in climate models (Tran et al., 2019). NASA's MODIS snow cover data is available since early 2000 following by Terra satellite launched on 18 December 1999 and MODIS Aqua was launched on 4 May 2002 (Riggs et al., 2017). The remote sensing data is important for SCE in mountainous area since the topographic condition make the observation limited in high altitude. Further, more accurate understanding of SCE is important for water resource management and hydrological modeling for the mountainous basins.

About 3000 separate glaciers with an area of ~2700 km^2 exist in Afghanistan. The accumulation of snow in highlands during winter melts and runoff during spring and summer, or remains throughout years and becomes glacier river of ice within few years (Shroder & Ahmadzai, 2016, p. 15). Most of the precipitation occurs during winter in snow and rain form. Afghanistan economy depends mainly on the agriculture with 20.5% of GDP coming from the agriculture sector (NSIA, 2019, p. 150). Afghanistan receives erratic rainfall varies from 75 mm/yr in Farah to 1170 mm/yr in the South Salang (Reddy, 2019, p. 56).

Satellite image and remote sensing data are an alternative for snow cover mapping. In the past decades various number of satellite data are available, and many researches are conducted on snow cover mapping and relevant topics worldwide. As example, the Scanning Multichannel Microwave Radiometer (SMMR) on board Nimbuz-7 satellite, Special Sensor Microwave Imager (SSM/I), Defense Metrological Satellite Program (DMSP) were used for seasonal snow extent and snow mass from 1976-2006 in South America (Foster et al., 2009). Advance Scanning Radiometer for Earth Observation system (AMSR-E) boarded on the NASA Aqua satellite were used in Xinjiang, China from 2003 to 2010 (Dai et al., 2012). Advance Very High Resolution Radiometer (AVHRR) were used for driving long term snow cover extent for Central Asia from 2000 to 2009 (Zhou et al., 2013). Landsat data were used for construction of snow persistence map from 1985 to 2011 in northwest Alaska (Macander et al., 2015). Sentinal-1 and MODIS were used for monthly mapping of wet and dry snow from 2015 to 2017 in Himalayan river basin (Snapir et al., 2019).

MODIS Collection 6 (C6) commenced on May 2015. Since then, C6 snow cover algorithms and data product have been changed significantly and data content have been increased compared to Collection (Riggs et al., 2016). The revisions in C6 was mostly focused on the snow detection under clear sky condition, as well as dramatic improvement of snow/cloud differentiation (Riggs et al., 2016).

The Normalized Difference Snow Index (NDSI) was introduced by Crane and Anderson (1984) for Experimental Metrological Satellite Program (DMSP) and later Dozier (1984) used Landsat band 2 and 5 in a similar study (Dietz et al., 2012). The NDSI technique for snow detection has proved to be a sturdy indicator of snow globally as numerous research evidences by who used the MODIS snow product and reported the accuracy statistics in a range of 88-93% (Riggs et al., 2016). MODIS C6 snow cover products are based on NDSI technique:

$$NDSI = \frac{b_4 - b_6}{b_4 + b_6} \qquad (1)$$

where, b_4 and b_6 refer to MODIS bands 4 (0.54-0.56 μm) and bands 6 (1.62-1.65 μm) respectively. Because the Aqua MODIS band 6 is non-fractional, NDSI Aqua is calculated using bands 7 (2.10-2.15 μm).

Due to high cloud coverage, satellite snow cover products, in general, cannot be used directly as source data in water resource management and hydrological modelling. Therefore, the main objective of this study is to produce SCE from MODIS Aqua and Terra NDIS snow cover product C6.

2. STUDY AREA

Afghanistan is divided into five major river basins; Kabul (Indus), Harirod-Murghab, Hilmand river basin, Amu Darya, and Northern river basins as shown in Figure 1(b). The Northern river basin consists of four sub-basins; Shirin Tagab, Sari Pul, Balkhab, and Khulm river basins as shown in Figure 1(c). Balkhab River basin (BRB) as the study aera, starts from highlands in the central Afghanistan and flows through flat lands in the northern Afghanistan. Elevation of BRB ranges from 241 to 4621 m (Figure 1(a)). Northern river basin is divided into rainfed area and irrigated oases from agro-ecological point of view (MAIL. Atlas, 2004). The Northern river basins are usually dry-out inside Afghanistan border in the sand desert and irrigation channels, and flow to the Turkmenistan low lands in case of extreme events. The rainfall occurs mostly in the winter season from February to April with (200-400 mm/yr) in the northern parts of Afghanistan (Reddy, 2019).

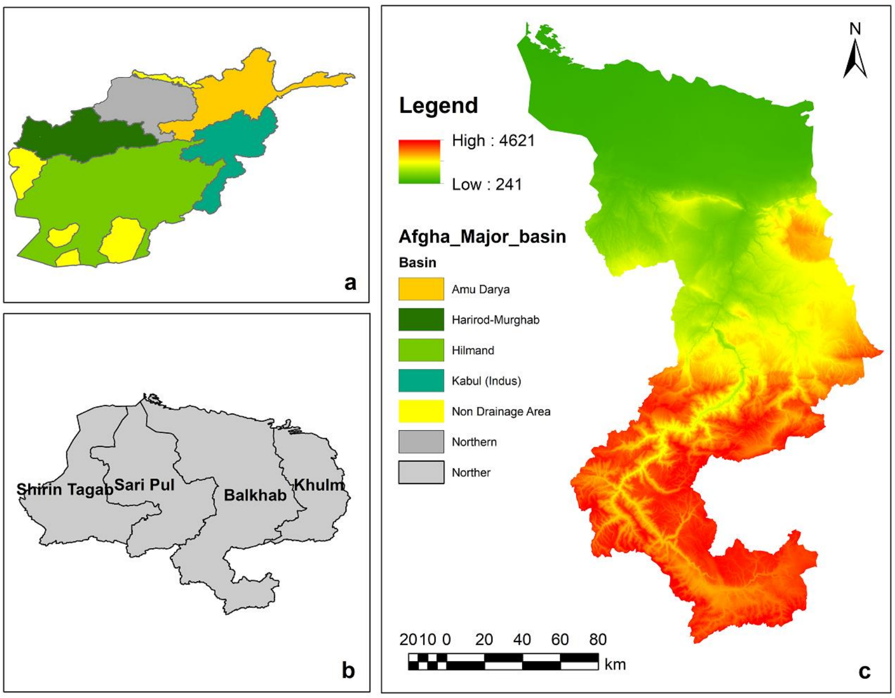

Figure 1. Study area, a) The major five river basins in Afghanistan, b) the Northern river basin and its four sub basins including the BRB, and c) Balkhab River basin (BRB) and its elevation.

3. MATERIAL AND METHOD

3.1 Data

MODIS NDSI snow cover C6 were collected and used for this study as the input files. MODIS Aqua and Terra daily NDSI snow cover products were downloaded from LP DAAC website for the period from Jan. 2010 to Dec. 2018. The Landsat 8 bands 3 and bands 6 were downloaded from 28 May 2013 to 26 October 2018 for the validation purposes. Table 1 shows the data sources and spatial resolutions of the input dataset.

Table 1. Summary of input data sources

Data	Resolution	Retrieved
snow cover (MOD10A1)	Daily NDSI Snow cover map with 500 m spatial resolution	(https://lpdaacsvc.cr.usgs.gov/appeears/)
snow cover (MYD10A1)	Daily NDSI Snow cover map with 500 m spatial resolution	(https://lpdaacsvc.cr.usgs.gov/appeears/)
Landsat 8 images	30 m spatial resolution	(https://earthexplorer.usgs.gov/)

3.2 Methodology

3.2.1 Snow cover mapping

The MODIS Aqua and Terra daily NDSI snow cover C6 were used as the input. The MODIS Aqua and Terra observe the same area of earth approximately three hours apart. The tandem work of these sensors gives the opportunity to optimized cloud-free surface observation. The difference in orbit and time of the earth surface capture by MODIS Aqua and Terra and the fact that the clouds are dynamic help the investigator to make new maps from combination of both Aqua and Terra with less cloud coverage. For this study, MODIS Aqua and Terra were processed based on the MODIS user's manual, and images were reclassified to land, snow, no-decision, missing data, water, cloud, and detector saturated for both MODIS Aqua and Terra. The processed reclassified files were subjected to the automatic combination with aid of python. The combination was based on the assumption that no snowfall or snowmelt will occur during the time period that MODIS Aqua captures the same area which was captured by MODIS Terra. The cloud pixels in MODIS Terra were replaced with the same pixels from MODIS Aqua with three possibilities; a) if the cloud pixels are any other classes in the MODIS Aqua, the cloud will be changed to it, b) if the same pixels are clouds in both Aqua and Terra, it will remain as cloud, c) In case only Aqua or Terra captures the area for an specific day, the existing image will be accepted as the SCE map for that specific day. MODIS Aqua and Terra combined files were improved from the perspective of the cloud obstruction. However, the cloud coverage still covered the study area significantly especially during the winter and early snowmelt season.

The fact that solar radiation is the main cause of the snowmelt can derive another assumption for the image combination. Since the cloud can reflect a huge portion of solar radiation, second assumption is neglecting the snowmelt as well as snowfall within 24 hours under the cloud pixels. Based on this assumption the MODIS Aqua and Terra combination (A/T combination) were subjected into two more temporal combinations; 1) combination of A/T combined images with its proceeding day, and 2) combination of A/T combined images with its previous day. The temporal combinations were also conducted just for the cloud pixels such that, if the same pixels were classified as non-cloud pixels during 24 hours before or after, they were replaced to the other classes.

3.2.2 Validation of processed snow cover extent

Validation with the observation is the best practice for reliability of data as far as the observe data is available. However, due to the data scarcity in Afghanistan, the processed MODIS SCE products were validated with Landsat 8 images. The Landsat bands 3 and bands 6 were used to produce SCE using the NDSI technique.

Pixel-by-pixel comparison was conducted for the MODIS and Landsat 8 NDSI products. The direct pixel-by-pixel comparison shows an agreement of 86.47% in average for the period from 21 May 2013 to 13 December 2014. Since the cloud pixels were not removed completely from the MODIS snow cover maps, the cloud pixels were acting as an obstacle for the comparison between MODIS and Landsat 8 NDSI products. In addition to the pixel-by-pixel comparison, the confusion matrix was used for accuracy assessment.

Confusion matrix is a summary of prediction result on a classification problem to describe the performance of classification model (Cabrera & Lee, 2018, 2019, 2020). The overall accuracy (ACC) from the confusion matrix can be obtained by the Eq. (2)

$$ACC = \frac{TP + TN}{TP + TN + FP + FN} \quad (2)$$

where TP, TN, FP, and FN are condition true positive, true negative, false positive, and false negative respectively. In the confusion matrix, MODIS snow cover pixels were compared as the predicted with Landsat 8 snow cover pixels as the observed. If land and snow pixels are matching in both observed and predicted, the pixels were assigned as true positive. If the pixels are snow in the observed and land in the predicted, the pixels were assigned as false positive. If the pixels are snow in the predicted and land in the observed, the pixels were assigned as false negative. If the pixels are land or snow in the observed and any other classes in the predicted, then it was assigned as true negative. Table 2 depicts the summary of confusion matrix for pixels conditions. Table 3 exhibits the validation result for the entire validation period. The average ACC from the confusion matrix for the validation period is 89.37%, being improved from 86.47% by the pixel-by-pixel comparison.

Table 2. Confusion matrix summary table for comparison of Landsat 8 and MODIS NDSI snow cover products

Observed	**Predicted**	
	Snow and Land match	Snow and Land not match
Snow and Land match	True Positive	False Negative
Snow and Land not match	False Positive	True Negative

Table 3. Validation results from pixel-by-pixel comparison and confusion matrix

Date	**Pixel-by-pixel examinations**	**Overall accuracy from confusion matrix**
2013-05-21	95.77%	99.03%
2013-11-13	95.13%	95.32%
2014-02-08	88.73%	89.19%
2014-04-13	91.63%	93.75%
2015-05-15	97.42%	97.42%
2014-11-23	91.43%	92.13%
2014-12-09	87.17%	91.46%
2015-01-03	76.28%	82.36%
2015-02-04	78.03%	80.98%
2015-03-08	89.22%	93.98%
2015-04-25	78.80%	79.01%
2015-11-26	92.45%	92.91%
2015-12-28	83.10%	83.88%
2016-02-14	79.64%	81.56%
2016-03-26	85.33%	91.73%
2016-04-11	71.39%	93.65%
2016-05-13	97.65%	97.82%
2016-11-05	83.90%	84.07%
2016-12-31	84.02%	88.75%
2017-02-25	85.71%	87.56%
2017-03-04	92.15%	92.64%
2017-12-10	80.78%	83.49%
2018-02-03	77.81%	83.04%
2018-03-16	89.86%	90.43%
2018-05-26	97.63%	99.08%
2018-12-13	77.15%	78.47%
Average	86.47%	89.37%

4. Result

The results of three-step image combination for MODIS Aqua and Terra satellites are summarized in the Figure 2 and Figure 3. Figure 2 presents the cloud coverages over BRB from Aqua, Terra, A/T combination, temporal combination 1 (A/T +1day), and temporal combination 2 (A/T -1day) from 2010 to 2018. The cloud coverage is gradually reducing after each step of combination. In particular, the cloud coverage is reduced significantly after images were subjected to the temporal combination 1. In addition, the cloud coverages were mostly removed during the June to September where cloud coverage were in minimum. However, the cloud is still high during the months of January and February where most of precipitation occurs in the BRB. The highest monthly average cloud coverage was recorded during the months of January and February from 2010 to 2018 with an approximate range of 70-80% of total area. The three steps combination reduced the monthly average cloud coverage to less than 35% during the cloudiest months over the BRB. The average cloud coverage for the MODIS Aqua and Terra from 2010 to 2018 were recorded 37.6% and 31.8% respectively. The three steps combinations reduced the cloud coverage during the study period to 8.9% of the total area.

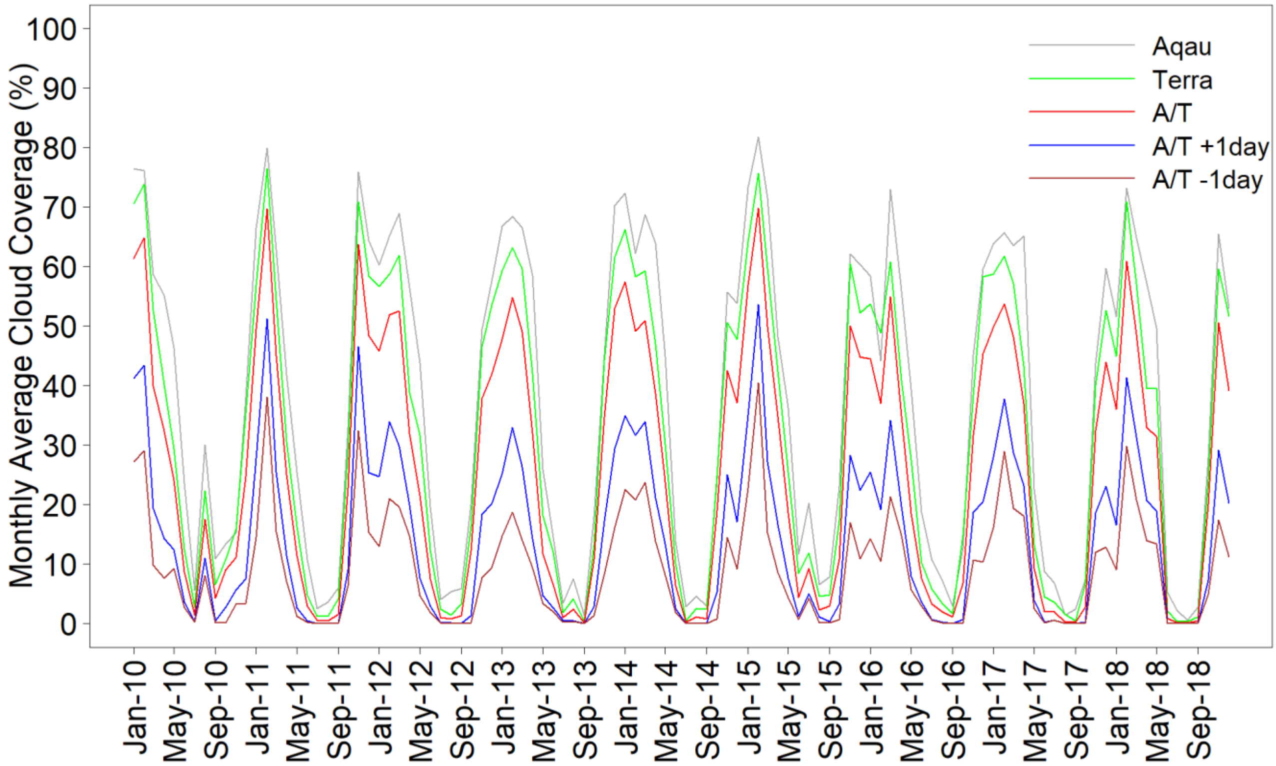

Figure 2. Cloud coverage (%) over BRB at each step of combination. A/T denotes the processed product from Aqua and Terra combination. A/T+1day and A/T-1day denote the processed products from the temporal combination 1 and 2, respectively.

Figure 3 shows the monthly average snow coverage of the BRB for the period of 2010 to 2018. After each combination the result shows that snow covered area is increasing. This increment in snow cover area is because cloud formation happens in high altitude in the southern mountainous of BRB as well as long-last-snow for later melting also accumulates in the high-altitude part of BRB. As cloud pixels are eliminated, more snow pixels are added at each combination process in the snow cover maps. The snow coverage increases significantly after first temporal combination in the snow accumulation and melting season which starts from October and continued to the late May of the proceeding year. The snow covers are almost zero in during the summer and early autumn seasons.

5. CONCLUSIONS

This study was conducted to produce the SCE and snow cover map over BRB. The result shows that the optical satellite data from MODIS Aqua and Terra cannot be used directly as the source of data for the snow coverage. The improvement of the images using image combinations or any other remote sensing techniques is essential to reduce the cloud coverage/pixels from the snow cover products for any further use. As a result of combination processes, the cloud coverage over BRB were reduced to 8.9% from 37.6% and 31.8%, respectively, in MODIS Aqua and Terra NDSI snow cover product C6.

The result of this study can be used for the purpose of water resource management, hydrological modeling, and find the impact of global warming and climate changes over the snow resource on the mountainous area of BRB and Afghanistan.

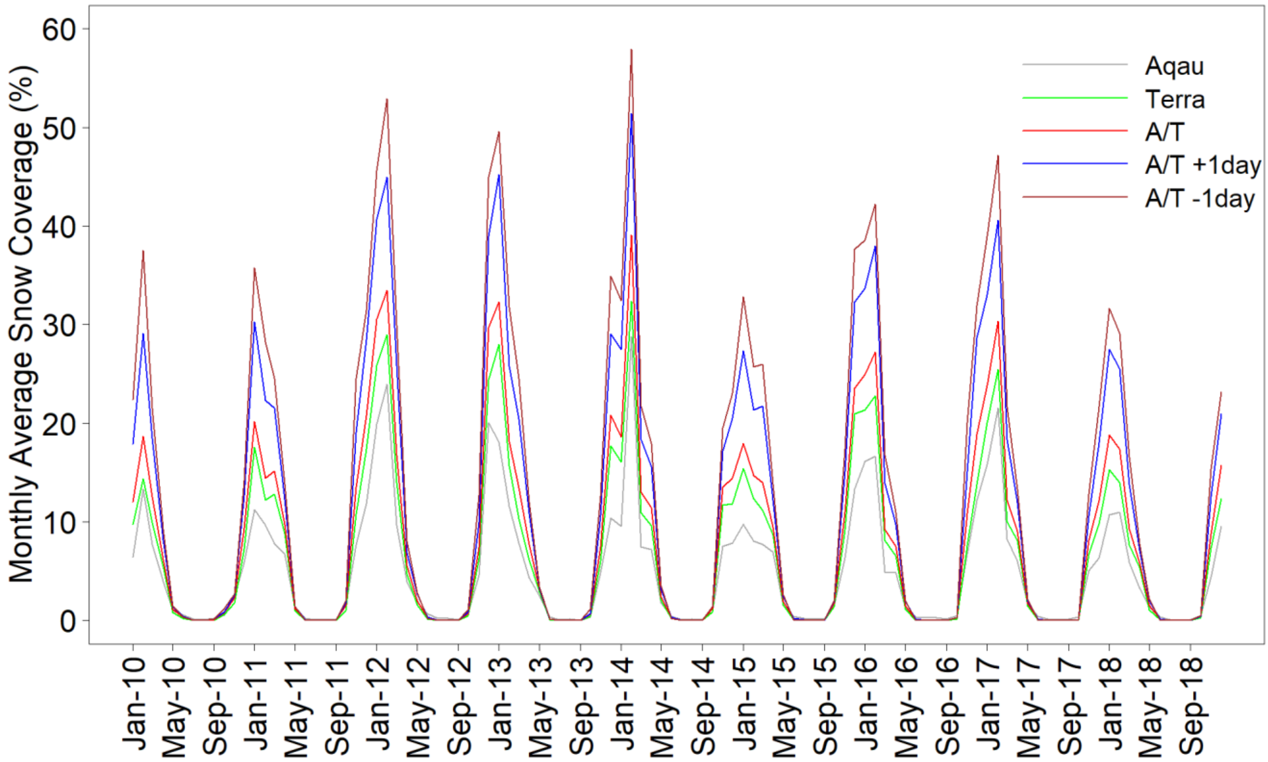

Figure 3. Snow coverage (%) over BRB at each step of combination. The legends indicate the same with Figure 2.

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