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The Application of Geographic Information System (GIS) and Remote Sensing in Quantifying Snow Cover and Precipitation in Kabul Basin

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Abstract

Water Resources availability is very important to social and economic well-being of the people and has huge impacts on the socio-economic scenarios of a country. Precipitation and snow cover area assessment is some of the major inputs in hydrologic modelling and also for assessing and managing water resources in a basin. The change in the water availability in a basin has huge socio-economic impacts because of the water usage for food production, industries, and many others. The main aim of this study was to measure the snow cover area and precipitation from 2001 to 2015 in the Kabul basin. Moderate Resolution Image Spectroradiometer (MODIS) and Tropical Rainfall measuring Mission (TRMM) data were used to study snow cover area and precipitation respectively during 2001-2015. 8-day snow cover product for 15 years (January) was used to analyse the snow cover while monthly data of TRMM (3B43) were used to analyse the rainfall from 2001-2015. Different image processing techniques were applied on the data retrieved using GIS and Remote Sensing softwares. Initially, SCA was seen increasing, but during the last 3-4 years, it kept decreasing gradually. Rainfall was initially recorded as low, while later on, it was recorded high and reached the highest during 2010.

Keywords: MODIS; Snow Cover; TRMM; Precipitation; Kabul Basin; Remote Sensing

1. Introduction

Snow cover area is an important component of a regional as well as global climate system and also a critical storage system of fresh water on the surface (Larson *et al*., 2009). Equally, precipitation is also one of the important input parameters for land surface hydrological modelling of a basin and its quantification is necessary for assessing available water resources (Zhang & Srinivasan, 2010). Both snow cover area estimation and precipitation quantification, thus, are important to assess the water resources.

Traditionally, snow cover is measured by monitoring the snow physically in a network which gives accurate information about the snow cover. However, the method is not feasible for long range measurement because of its spatial scale, i.e. the sparse network having very few stations as compared to the area which is unable to deliver the amount of information needed for the accurate snow cover estimation (Atif *et al.*, 2015). Similarly, rainfall is measured using rain gauges which give information about variations in trends of precipitation monthly. Nevertheless, because the rain gauges cannot be deployed in remote places and some areas are difficult to reach, they account for 25-30% of the surface of the earth (New *et al.*, 2001). Therefore, a mechanism is needed to monitor the snow cover and rainfall at a large spatial and temporal scale remotely (Ershadi *et al.*, 2005).

The modern satellite system in space has the capabilities to monitor different natural and human induced dynamics at different spatial, spectral and temporal scale (Daly *et al.*, 2012). These satellite systems operate round the clock and provide the captured data of almost all of the world for, mostly, free or at some nominal price. The data retrieved from these systems can be analysed for making policy decision including water supply and demand. The Moderate Resolution imaging spectroradiometer (MODIS) which was launched in 1999 has the capabilities to study the earth's geophysical phenomena, which include mapping the areal extent of snow using SNOWMAP algorithm (Hall *et al.*, 1995).

The SNOWMAP algorithm was developed by using thematic mapper data to automatically map the area extent of the snow using different MODIS bands on a daily basis. Different snow products of MODIS are available at national Snow and Ice Data center from September, 13, 2000 to date which include daily and 8 days snow cover (Hall *et al.*, 2001). Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA of United states of America and National space development agency of Japan, which measures the precipitation and energy exchange of tropical and subtropical regions (Kummerow *et al.*, 1998). TRMM Microwave Imager (TMI) and Visible and Infrared Radiometer system (VIRS) are primary rainfall measurement instrument on board on TRMM. Different products of TRMM are available online, including daily 3B42 and monthly 3B43 products.

Previous related studies argue that the relationship between snow, global warming, and land use can influence the changes in landforms (Beato Bergua *et al.*, 2019). Snowfall can be identified by using a two-dimensional model, so that disaster risk reduction can be optimized (Nakamura *et al.*, 2019). Snowmelt is affected by slopes and causes high infiltration (Miao *et al.*, 2019). MODIS-based vegetation maps can be used to calculate the capacity and intensity of snow in a basin (Pyankov *et al.*, 2018). The ASTER GDAM and Landsat 8 OLI images can be used to analyse the snowfall parameters (Kumar *et al.*, 2018).

Nevertheless, the previous studies did not consider the aspects of rainfall as water resources in the snow area, Therefore, it is necessary to study the use of GIS and remote sensing to improve the quality of water resources. The differences in the rainfall among the regions based on latitude are very important to know in relation to climate change. Hence, the main aim of this study was to measure the snow cover area and precipitation from 2001 to 2015 in the Kabul basin.

2. Methods

The Kabul river basin has a catchment area of approximately 94,000 sq. Kilometers. The river drains two countries, i.e. Pakistan and Afghanistan, and is located in the northwestern side of Pakistan and north eastern side of Afghanistan (Aziz, 2014). The river Kabul flows from east to west, ultimately joining the Indus River near Attock, in Pakistan Khyber Pakhtunkhwa province from where it finally merges into Arabian Sea (Lashkaripour *et al*., 2008). Many barrages have been constructed on various locations on the river to support the system of extensive agricultural irrigation. The economy of most of the people depends on agriculture. Although the basin comprises of 12% area of Afghanistan, it has 35% population of Afghanistan (Vick, 2014). Major portion of the population live in the area and, mostly, the population is concentrated along the main courses of the river and adjacent areas where water is available for agriculture the production of agriculture because the main source of income in that area is agricultural production. Most of the agriculture is depends on the river and, thus, is located along the adjacent areas where river water is accessible for irrigation purposes. The greater amount of water supplied in the summers results in intensive cropping in the area while some of the areas is also rain fed.

In this study, MODIS data were used for calculating the snow cover area. MODIS 8-days snow cover product with a spatial resolution of 500 meters, i.e. MOD10A2V6, is available at the National Snow and Ice Data Center NSIDC with a spatial resolution of 500 meters. The 8-daily product is generated from the daily snow cover product MOD10A1V6, which in turn is derived from Normalised difference snow index NDSI (equation 1). Snow cover has a high reflectance rate in visible bands and low reflectance rate in shortwave infrared SWIR. The Normalised difference snow index reveals those differencing high values show snow covered areas. Cells having NDSI>=0.4 are considered as the snow covered cells. Different Remote Sensing and GIS softwares (Table 1) were used for the processing of imagery and estimation of the snow cover area.

$$\text{NDSI} = \text{Band 4} - \text{Band 6}/\text{Band 4} + \text{Band 6} \qquad (1)$$

Table 1. Tools and data used for SCA assessment

Data/Tools	Details
MODIS Snow cover data	MOD10A2V6 (500 meters)
TRMM data	3B43 Monthly data mm/hr.
ArcMap 10.1.4	Collecting, Analyzing, Processing, and manipulating satellite imagery
Modis Reprojection Tool	Spectrally subsetting and reprojecting MODIS data

2.1. Reprojection

MODIS data were processed and generated as a gridded output in the sinusoidal SIN projection in the HDF format. The MODIS reprojection tool is used for a number of pre-processes on MODIS data, including the spatial sub setting, spectral sub setting, format conversion, and geographic transformation to a different coordinate system. MRT was used to spectrally subset the products and retain only those bands which were needed for further processing in the study. MRT was available online for processing MODIS datasets, in which the data were converted from sinusoidal to projected coordinate system to enable the measurement and then were converted to TIFF format so that the other softwares can conveniently read it.

2.2. Image processing

The aim of image processing using geospatial softwares is to extract the meaningful information from the images. Many open sources and commercial geospatial image processing softwares are available to use to process the different types of satellite imagery and extract the meaningful information from it. Some of the available softwares are Erdas Imagine, ENVI, IDRISI, and ArcMap. Although ArcMap is a GIS software having more capabilities for vector data processing, still it is used for different kinds of image processing .Images preprocessed through MRT were processed in ArcMap, where snow cover areas and non-snow cover areas were separated and the final snow cover areas from those images were extracted.

2.3. Precipitation data acquisition and processing

Tropical Rainfall Measuring Mission TRMM monthly product 3B43 version 7 was used for quantifying liquid precipitation in the study area. These data combined the daily data from TRMM and other satellites, and estimated the best possible estimate from the data at temporal resolution of one month. The data acquired from NASA was converted, reprojected, and extracted to study area using different GIS softwares. The data were rescaled to 500 meters spatial resolution. Many image processing and statistical techniques were applied on the data. TRMM 3B43 monthly data iswere available in unit of mm/hr,. which was then converted to mm/day, and subsequently to mm/month. Annual accumulated data as well as annual mean were generated using those monthly data.

2.4. Snow cover area (SCA) and precipitation quantification

Snow cover and non-snow cover areas were separated in the MODIS product. Moreover, the snow cover area was calculated for each image, which was further averaged over the month by using all the data acquired and processed. Similarly, rainfall was quantified for the study area by using monthly and annually accumulated and mean data, using different techniques.

2.5. Snow cover area (SCA) and precipitation Maps

The snow cover areas were estimated using 8-day MODIS snow cover product and the maps were also generated at the same interval. Four maps for each month were generated, i.e. the 1st to 8th day, 9th-17th day, 18th -25th day, and last from 25th to 3rd day of next month, which was the 3rd of February. The precipitation data was averaged manually and annual accumulated maps were produced by ArcMap.

3. Results and Discussion

The results show that during the initial years i.e. 2001 onwards, there was an increase in the snow cover area which could be seen up to 2006 and 2007. There were also minor increase and decrease in the snow cover area in the successive years up to 2011. From 2012 onwards, a gradual decrease could be seen in the snow cover area which was 65,285 sq. kilometers in 2012, 63,244 sq. kilometers in 2013, 56716 sq. km in 2014, and 50,935 sq. km in 2015. Researchers pointed out that the decrease in snow cover area in the next 10-15 years in Pakistan will be considerable (Zahid & Rasul, 2011). It might not be considerably noted in the initial years, but it was observed during the last 4 years, from 2012 to 2015. From 2008 up to 2011, an irregular pattern was observed in the snow cover change, which was neither decreasing gradually nor increasing gradually but increased somewhere and decreased at other times. As shown in Table 1 and Figure 1, the snow over area gradually increased from 50,856 sq. km in 2001 to 61,406 sq. km in 2006. The snow cover changed irregularly during 2007 up to 2011, which sometimes increased or decreased. This might also be attributed to the accuracy of the data used for the study. The snow cover area was recorded the highest in 2012, which was 65,285 sq. km, from where it went on decreasing gradually towards 2015.

Table 2. Accumulated snow cover area estimated from MODIS snow cover product

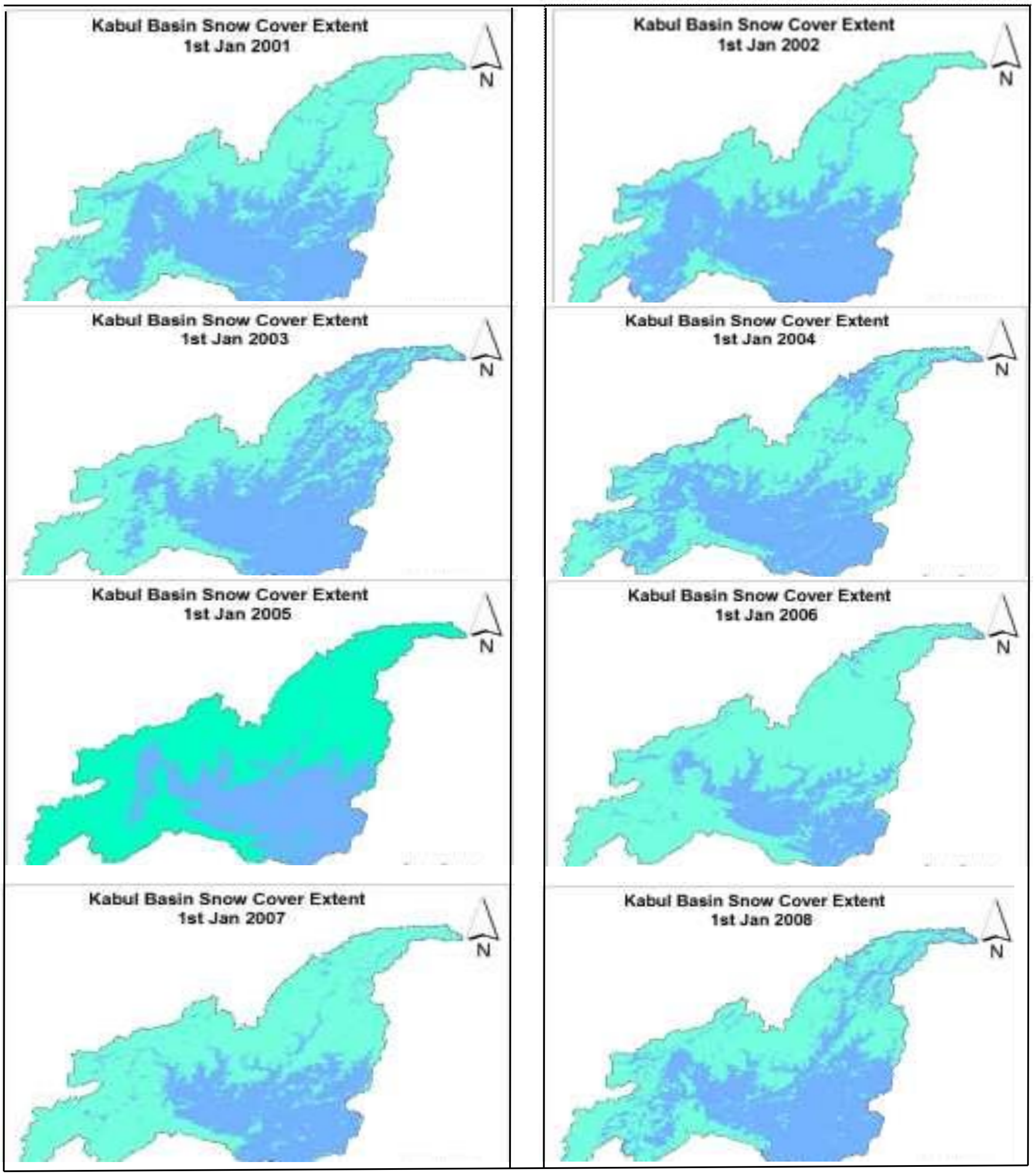
Year	Snow cover area (km^2)	Year	Snow cover area (km^2)
2001	50856	2009	57812
2002	50721	2010	51286
2003	54307	2011	45517
2004	55629	2012	65285
2005	57201	2013	63244
2006	61406	2014	56716
2007	61221	2015	50925
2008	49599		

Table 2 shows that there are fluctuations in the area covered by snow. This was due to changes in the rainfall and significant temperature differences. In 2012 and 2013, the area covered was very large due to the influence of changes in the duration and pattern of the rainy season.

Table 3. Mean Annual Rainfall of Kabul Basin Estimated from TRMM

Year	Mean Annual rainfall (mm)	Year	Mean Annual rainfall (mm)
2001	260.00	2009	599.34
2002	388.73	2010	676.43
2003	535.31	2011	584.91
2004	472.43	2012	556.61
2005	562.78	2013	648.75
2006	521.37	2014	654.67
2007	518.39	2015	642.01
2008	566.19		

The mean annual rainfall varied from 260 mm to 676 mm as shown in Table 3. In the initial years, just like the snow cover, less rainfall was recorded and was restively larger in the following years. The year 2010 received the largest amount of rainfall in all 15 years which caused Pakistan to suffer devastating floods in areas of Khyber Pakhtunkhwa, where large amount of crops were destroyed and suffered from around 1100 causalities (Sayama *et al*., 2018). the average rainfall in Table 3 does not directly affect the snow cover,. This is because the intensity of the rain also greatly influences the existence of run off. In areas with high rainfall intensity, rain will erode soil material quickly with higher exogenous power.



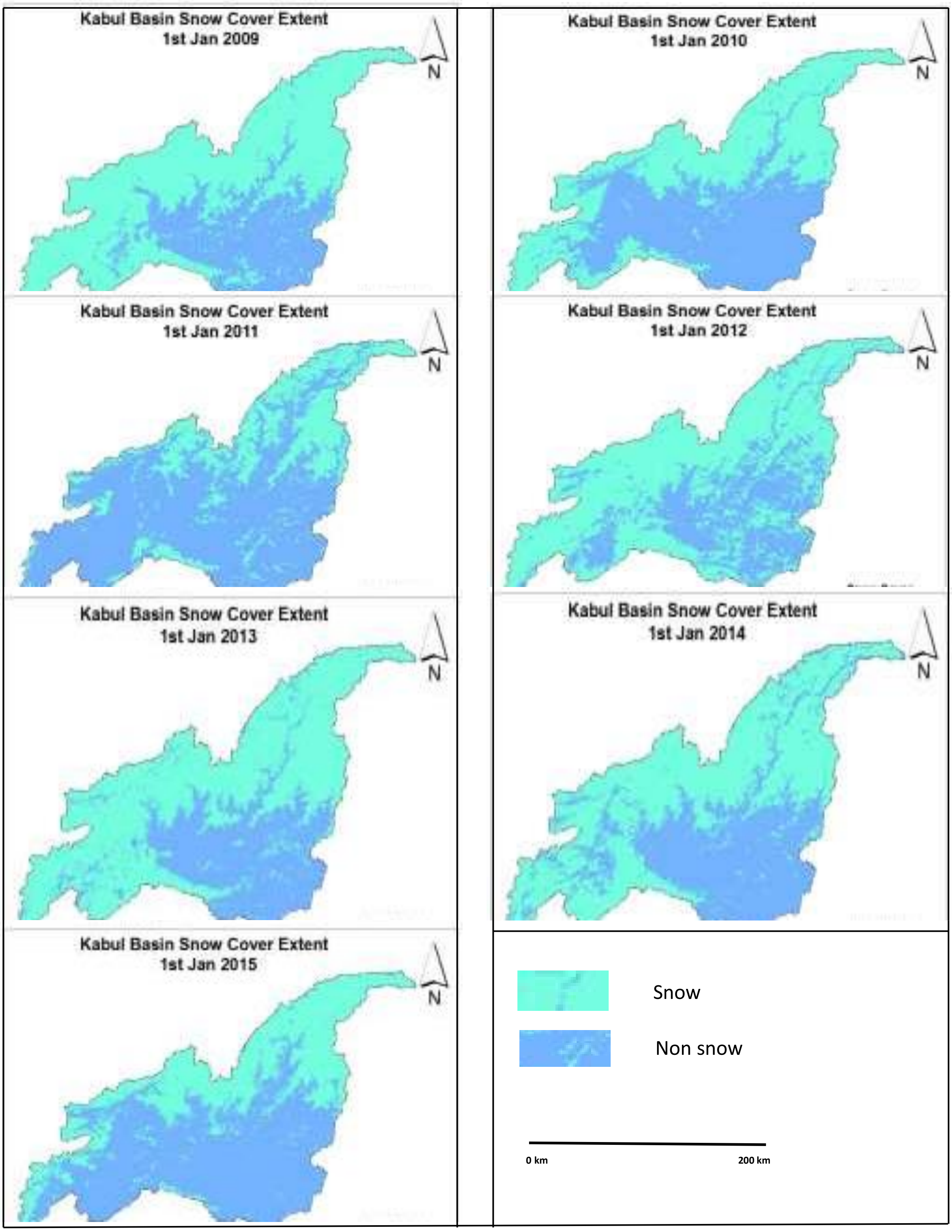


Figure 1. The expansion of the area covered by snow

Figure 1 shows the expansion of the area covered by snow over time. It shows that there are human interventions on the environment that cause climate change and snow expansion. Areas that have steep slopes will be a source of melt snow that flows with high intensity to other areas; hence, there is a need for conservation efforts to overcome this.

When the rainy season is too short, snowmelt can cause changes in landforms with different impacts on the environment.

The result of the previous research that can be compared to the results of this study is the need for water that comes from snowmelt when summer is very high, as it shows that snow has an impact on people's lives during the summer (Amstrong *et al.*, 2019). Microclimate greatly influences snow characteristics in an area, so the is a need for differing planning to cope with too high rainfall (Plach *et al.*, 2019). Meltsnow is the most influential source of irrigation in the area before the rainy season (Biemans., 2019). Meltsnow can increase run off so that it will significantly cause changes in the landform (Il Jeong & Sushama, 2018). Higher soil erosion occurs when there is snow when compared to the rainy season, so there needs to be a different conservation effort for the two seasons (Wu *et al.*, 2018).

Compared to the results of the previous studies, the advantage of this study lies on the temporal comparison in the low latitude region. With different rainfall, it is necessary to have different conservation in each watershed in this region. Areas with higher sun exposure will affect snow characteristics, especially the ones which exposed to erosion and run off. Watershed conditions that have a varied microclimate will have an impact on the diversity of vegetation and human activities.

4. Conclusion

Remote Sensing satellites have the capabilities to sense different phenomenon on the surface of earth from space. Their data availability, reliability, and cost have defeated many conventional techniques to acquire data for analysing different processes on the surface of earth. It is also Ssimilar to the case of Snow Cover Area Aassessment and Rainfall Quantification, The conventional techniques may be accurate and useful, yet they are quite expensive and, sometimes, unreliable because of human induced factors or some other effects. Although satellite images are free of charge and are available on the daily basis, still, the choice of selecting the specific source of data needs much analysis and study on the analyst’s side. Thise study found no considerable change in the snow cover area in the initial years, but later on in the last 3-4 years, it found a gradual decrease in the snow cover which might be due to the changing snow cover accumulation periods. Related to rainfall, variations were found in which less rainfall were recorded in the initial years and, later on in 2010, the highest rainfall was recorded in which Pakistan experienced devastating floods.

Conflict of Interest

The authors declare that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the article.

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