RESEARCH ARTICLE

- Vol. 5, No. 3 (Summer 2024)
- Pages: 63 – 70
- p-ISSN: 2791-0245
- DOI: 10.55737/qjssh.571394499
- e-ISSN: 2791-0229

Open Access

QLANTIC JOURNAL OF SOCIAL SCIENCES AND HUMANITIES

# Socio-Economic Implications of Snow Cover Area in the Upper Indus Basin

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**Abstract:** *The Indus River, one of the principal waterways in Asia, specifically the Indian Subcontinent, originates from the Himalayan Region and Qinghai-Tibet Plateau. Understanding snow cover dynamics is one of the most vital components for effective hydrological resource management and assessing the impacts of local, regional, and global climatic variations. Variations in the radiation of snow microstructures and snowpacks have profound socio-economic and environmental consequences, affecting agricultural productivity, reservoir supply for factories, environmental sustainability, governance of land resources, and overall community resilience. Fluctuations in snowmelt patterns can lead to water shortages or surplus, influencing food security and economic stability in a country largely dependent on agriculture. Utilizing Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data, this study assesses the implications of Snow Cover Area (SCA) on water security and livelihood of agricultural-related sectors. A comparative analysis of snow cover reveals a shifting trend in the accumulation period, with notable anomalies affecting the agricultural output, which affects the household income related to the agricultural sector. This research underscores the necessity of adapting water management strategies to align with evolving snow cover dynamics to mitigate potential socio-economic risks.*

**Key Words:** Snow Cover Area (SCA), Socio-economic Implications, Household Income

## Introduction

Traditionally, measuring seasonal snow involves physically monitoring snow cover through a network of ground-based meteorological stations, such as conducting snow surveys along designated snow courses. While snow surveys provide precise information about seasonal snow cover, their spatial scope is limited (Joshi R et al., 2015). In many regions, the limited nexus of weather depots fails to provide adequate information for creating longstanding data on snow for wider regions.

Satellite-based Surveillance of Earth offers significant potential for assessing snow dynamics on various scales, especially given the challenging and remote locations of many snow-covered areas. While examining, it can be observed that Snow is medium absorbent in the NIR band and has high reflectivity in visible bandwidth. Currently, several electromagnetic radiation-based sensors have been made available for monitoring and mapping snow on scales ranging from local to continental, including the Advanced Very High-Resolution Radiometer and the Moderate Resolution Imaging Spectroradiometer ( (Wardlow et al., 2012).

The seasonal snow cover is one of the crucial water resources in the arid and semi-arid regions. Over one-sixth of the global population looks at the seasonal snow and glacier meltwater to fulfill their water supply needs. The Indus River, one of South Asia's major waterways, originates from the Tibetan Plateau and the Himalayas, where the snow grain size can be measured by the spectral angel method (Negi et al. 2013). Tarbela is the first major storage structure on the Indus River, providing water flow to the Indus Irrigation System, which irrigates the agricultural lands of Punjab and Sindh provinces in Pakistan, the country's leading agricultural producers. The vigorous water-covered area of the Upper Indus Basin (UIB) endures within the high-pitched Karakoram and Himalayan ranges. Many studies have indicated that the

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- To Cite: Hameed, K., & Qureshi, S. H. (2024). Socio-Economic Implications of Snow Cover Area in the Upper Indus Basin. *Qlantic Journal of Social Sciences and Humanities*, 5(3), 63-70. https://doi.org/10.55737/qjssh.571394499

Upper Indus River, which is contributed by seasonal stabilized snowfields and glacial covered areas, covers more than 65% of the average annual flow above 3,500 meters in elevation. Approximately 90% of the lowland flow of the Indus River System arrives from the origin of the Hindu Kush, Karakoram, and western Himalayan mountains, making snowmelt an essential water source for Pakistan (Hasson et al., 2014). The major portion of the lowland flow of the Indus River system, i.e., 90%, comes from the origin of the Karakoram and the western part of the Himalayan mountain range, which makes the meltdown of this snow an essential source of water for Pakistan.

There is a fourth assessment report, which was published by the Intergovernmental Panel on Climate Change (IPCC) in 2007, highlighting the severe consequences of global warming on the resources of water in Pakistan. The report predicts that the drop in the area of snow cover observed in the last few decades is expected to improve in coming years, thereby decreasing the availability of water, reducing the potential of hydropower for Pakistan, and altering the seasonal flow and duration of flows in regions dependent on snow and glacier meltwater. The Asian high mountains contain the largest density of ice outside the Polar and Alaskan areas, yet relatively scant information is available about snow dynamics in these areas.

Moreover, this study further investigates the economic impacts of variation in Snow Cover Area (SCA) in the Upper Indus Basin (UIB). Besides, reduced snow cover could lead to earlier snowmelt, decreasing water availability during crucial agricultural seasons, which may lower crop yields and increase water scarcity, thereby impacting food security and farmers' incomes. Additionally, hydroelectric power plants, which rely on glacial meltwater, could face reduced water flow, leading to lower power generation, higher energy prices, and disruptions in energy supply. The tourism industry, particularly winter sports, could also suffer from diminished snow cover, potentially causing economic downturns in local economies dependent on tourism. Overall, these changes highlight the need for adaptive strategies to mitigate the economic downfalls and challenges posed by climate change in this region.

## Objectives of the Study

The key objectives of this research are as follows:

- To do systematic mapping and analysis of the variations in the Snow Cover Area (SCA) in the Upper Indus Basin (UIB).
- To investigate the socio-economic implications of Snow Cover Area (SCA) in the Upper Indus Basin (UIB) by employing the Moderate Resolution Imaging Spectroradiometer tool.

## Contribution of the Study

This study is a pioneer attempt to measure the Snow Cover Area (SCA) in the Indus Basin (UIB) by analyzing the socio-economic implications of climate change in this area. Besides, the outcomes of this research are specifically crucial and relevant for the policymakers, agricultural planners as well as water resource managers whose decisions majorly rely on precise and up-to-date information on snow cover to make informed decisions. Moreover, this study sets a precedent for future research focused on assessment and monitoring the environmental changes in similar regions by employing MODIS data, hence contributing to the global understanding based on climate change and its regional impacts. The meticulously gathered MODIS satellite data for the year 2013, compared to the data of the year 2003, ensured that the assessment captured the temporal variability of snow cover in the Upper Indus Basin (UIB). This dataset enabled the detection and quantification of shifts in snow cover extent, which are essential for comprehending the broader implications of climate change in the region. Furthermore, this study is a pioneer in analyzing the socio-economic implication of Snow Cover Area (SCA) in the Upper Indus Basin (UIB).

## Study Area

The study area encompasses numerous sub-basins of the Upper Indus Basin (UIB), situated among the source of the Indus River and the Tarbela Reservoir, including approximately 175,000 square kilometers. The main tributaries in the Upper Indus Basin region comprise the rovers of areas, i.e., Gilgit, Hunza, Shyok, Chitral, Swat, Kabul and Astore to be specific. The Upper Indus Basin forms a significant area of the Hindu Kush-Karakorum-Himalaya region, making this study a breakthrough in terms of socio-economic implications.

## Data Acquisition

1. MODIS data with a 250 m resolution was used.
2. Products were MOD10A1V5 (MODIS/Terra Snow Cover Daily L3 Global 500m Grid) and MOD10A2V5 (MODIS/Terra Snow Cover 8-Day L3 Global 500m Grid).
3. These products have been created using middle infrared, near-infrared, and red channels.

## MODIS Specifications

### Table 1

*MODIS specifications (Barnes et al., 1998)*

| | |
|---|---|
| Orbit | Altitude: 705 km<br>Node: 10:30 a.m. descending (Terra) or 1:30 p.m. ascending (Aqua)<br>Type: Sun-synchronous, near-polar, circular |
| Scan Rate | Speed: 20.3 rpm<br>Direction: Cross-track |
| Swath Dimensions | Cross-track: 2330 km<br>Along track at nadir: 10 km |
| Telescope | -Diameter: 17.78 cm<br>Type: Off-axis, afocal (collimated)<br>Feature: Intermediate field stop |
| Size | Dimensions: 1.0 x 1.6 x 1.0 m |
| Weight | Mass: 228.7 kg |
| Power | Consumption: 162.5 W (single orbit average |
| Data Rate | Peak: 10.6 Mbps (daytime)<br>Average: 6.1 Mbps (orbital) |
| Quantization | Resolution: 12 bits |

## Methodology

An index is created by employing the raw MODIS spectral bands, which are comprised of short-wave infrared and visible bands, in order to enhance snow cover mapping abilities (Justice et al., 2002). The methodology is given as follows:

Begin by stacking the image in Erdas. Imagine using imagery of multiple bands downloaded from USGS.

### Figure 1

*Showing stacked imagery of MODIS*

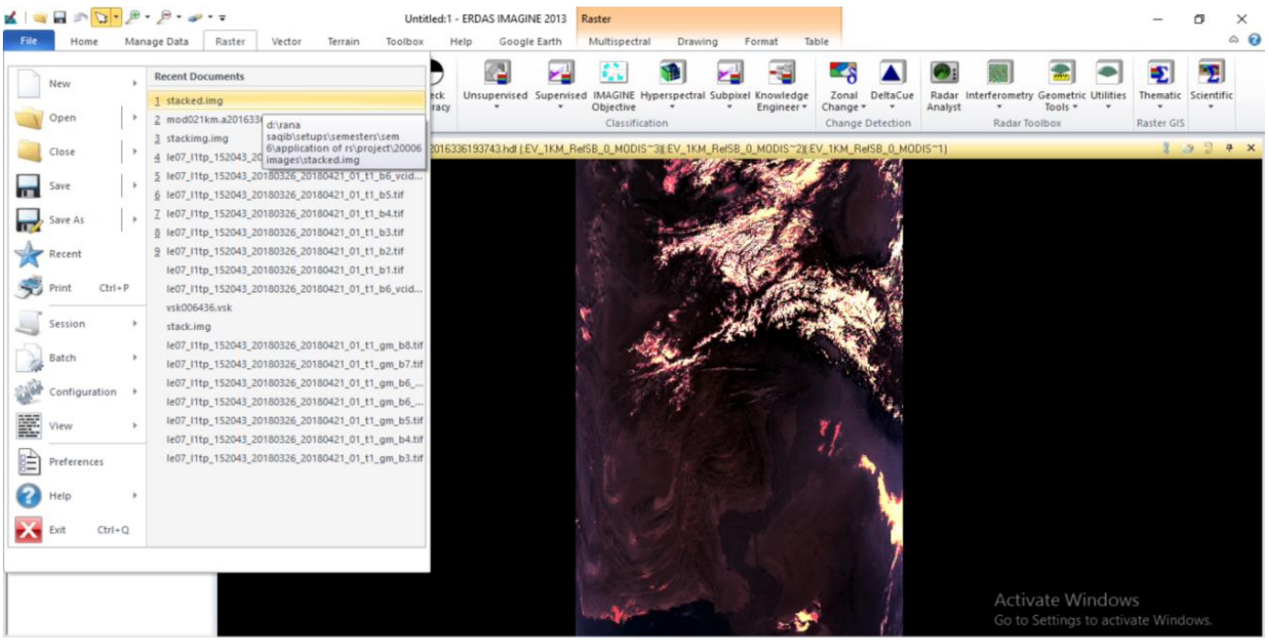
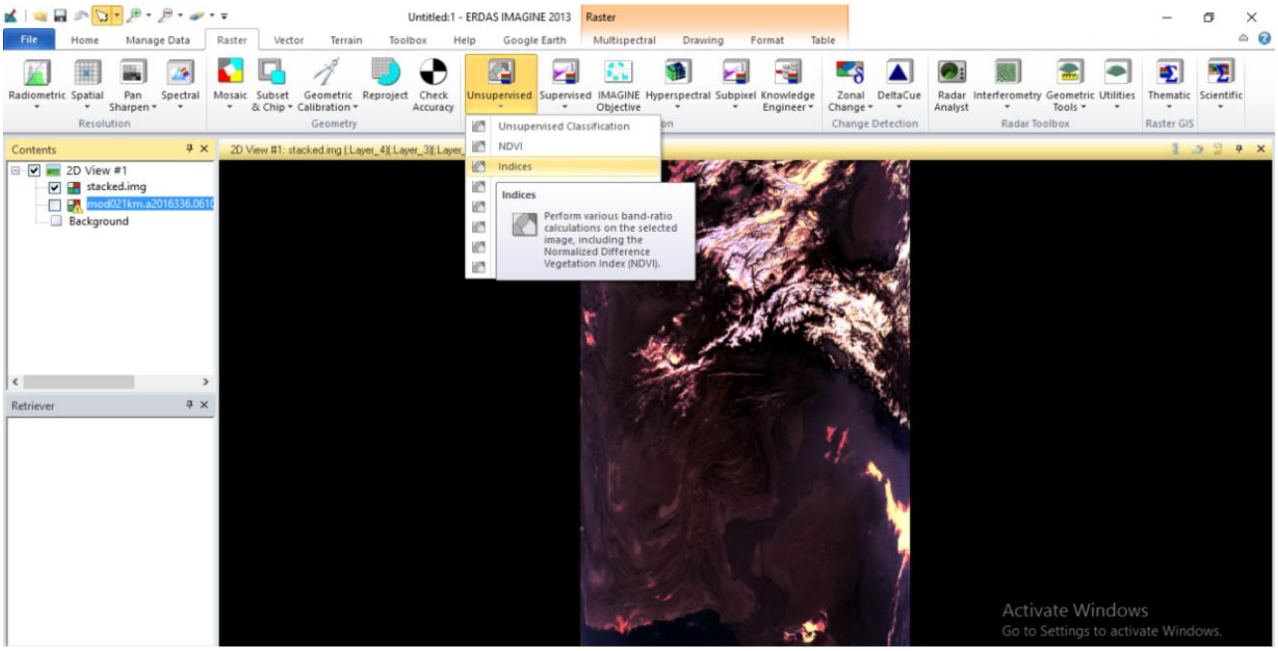


**Figure 2**

*Showing indices toolbar for applying NDSI*




Once the imagery is stacked, the NDSI (Normalized Difference Snow Index) is applied using the indices tool. MODIS is one of the crucial tools used to address the Normalized Difference Snow Index. The Normalized Difference Snow Index is a prototype of normalized difference indices originating from the well-known Normalized Difference Vegetation Index (Hegi et al., 2013). This index artfully exploits the interaction of snow with electromagnetic radiation. Snow exhibits a high level of reflectivity in the visible areas of the electromagnetic spectrum and significant absorption in the mid-infrared region. Furthermore, in the same region of the electromagnetic radiation (EMR) spectrum, clouds are, on average, more reflective than snow. This difference helps to discriminate snow from clouds at the 1.65 µm wavelength of electromagnetic radiation. However, using this technique, cirrus clouds remain troublesome when compared to snow. The numerical expression of the Normalized Difference Snow Index is given below:

**Figure 3**

**NDSI Algorithm**

At-satellite reflectances in MODIS bands 4 (0.545-0.565 µm) and 6 (1.628-1.652 µm) are used to calculate the normalized difference snow index (NDSI):

$$\text{NDSI} = \frac{\text{band 4} - \text{band 6}}{\text{band 4} + \text{band 6}}$$

Because Aqua's channel 6 detectors are damage, channel 7 (2.105 – 2.155 µm) is used instead.

$$\text{NDSI} = \frac{\text{band 4} - \text{band 7}}{\text{band 4} + \text{band 7}}$$

A pixel will be mapped as snow if the NDSI is $\geq$ 0.4 and reflectance in MODIS band 2 (0.841-0.876 µm) is > 11%. However, if the MODIS band 4 reflectance is < 10%, then the pixel will not be mapped as snow even if the other criteria are met, thus eliminating water bodies that have an NDSI > 0.4.

A "thermal mask" using a split-window technique (bands 31 and 32) is used to remove spurious snow cover, for at-satellite temperatures > 277 K (283 K for Collection 4).

An "impossible snow mask" is also used.

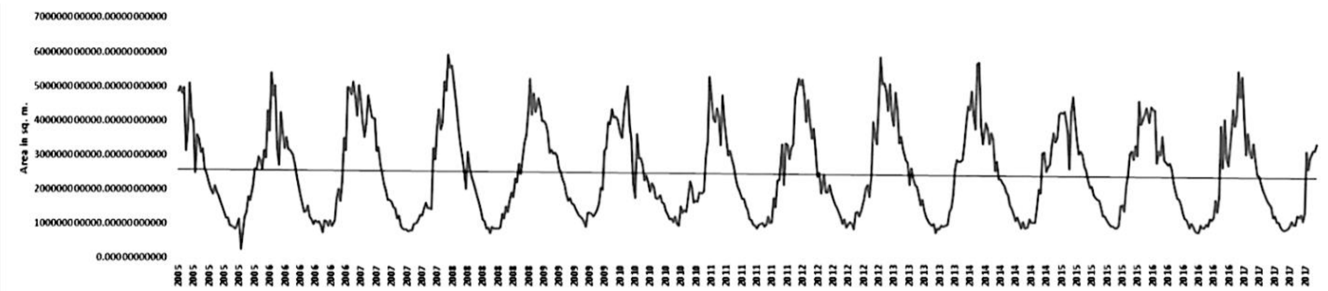
## Results and Discussion

The climate of the Upper Indus Basin (UIB) has been impacted by high maximum temperatures, leading to a rise of 0.93°C overall and a rise of temperature of approximately 1.3 °C in Northern Pakistan. This rise in temperature has caused glacier retreat and snow melting in the Hindu Kush-Himalaya (HKH) region. The primary causes are Western disturbances and monsoons, which have altered the UIB's weather patterns (Tariq et al., 2012). Maps show that snow melts from March to September, with high temperatures depleting snow cover areas, specifically at lower elevations (3000–5000 m) in the Hindu Kush Himalayan southwest and southeast areas. However, at higher altitudes in the UIB, particularly in the northeast, snow remains year-round, sustaining renowned glaciers like Baltoro, Biafo, and Siachen. Without increased rainfall from oceanic evaporation, glacier retreats in Pakistan and Afghanistan are expected to be significant in the next 10 to 15 years.

Snow accumulation begins in October and continues until February, covering the northeast and northwest areas due to westerly winds. This study shows a year-round retreat in snow cover for 2013, except in November, January, and February, compared to 2003. The meteorologist Amin mentioned in the report that the season of snowfall has been declining recently, only to January and February, down from five months (November to March). The data illustrates that the initial period of snow is at the beginning of October, and it is sustained until the middle of March. The meltdown of snow started by the end of March, and it significantly declined to its lowest point during the month of September (Atif et al., 2015). Moreover, the real difference in snow cover area is measured for the time period from 2005 to 2017, which is illustrated in the graph.

**Figure 4**

*Upper Indus snow cover area (SCA) derived by MODIS*




## Normalized Difference Snow Index (NDSI)

In contrast, clouds are more reflective than snow in the same mid-infrared region, specifically around 1.65 micrometers. This difference in reflectivity allows for the discrimination of snow from clouds. However, differentiating between snow and cirrus clouds remains challenging using this technique. Where "Green" represents the reflectance in the green portion of the spectrum, and "SWIR" represents the reflectance in the short-wave infrared region. This formula allows for the effective mapping of snow cover by highlighting the unique spectral properties of snow (Hall et al., 2010).

**Figure 5**

*Map result of normalized difference snow index (NDSI)*

Image 1

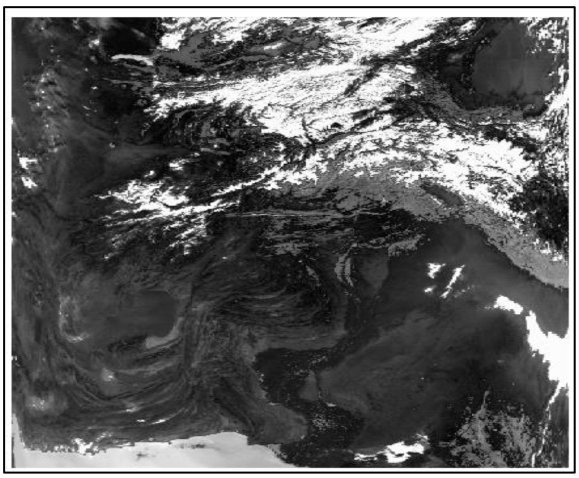
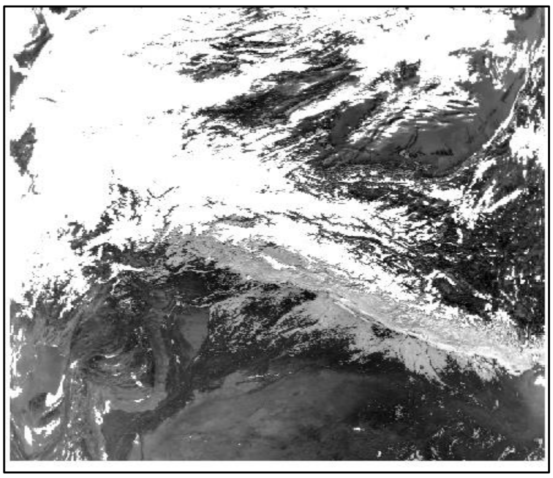


Image 2



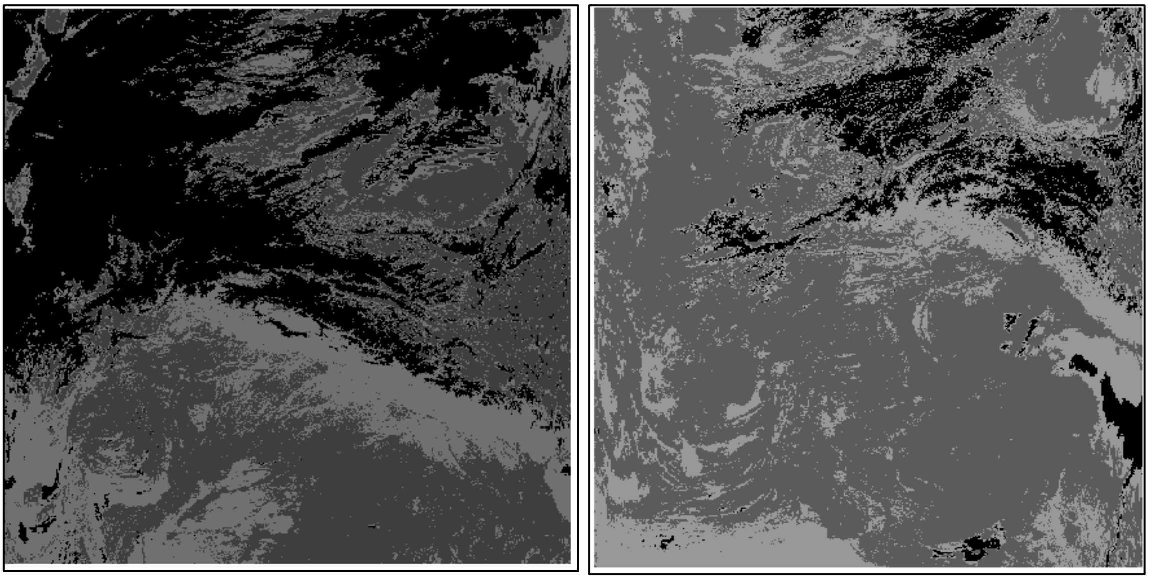
## Iso Clustering

In unsupervised classification, ERDAS IMAGINE utilizes the ISO clustering technique, which we employed to statistically analyze the data. This method measures the differences in the pixel values, which helps us group the pixels into distinct classes.

**Figure 6**

*Map result of Iso-clustering by unsupervised classification*

Image 1 Image 2



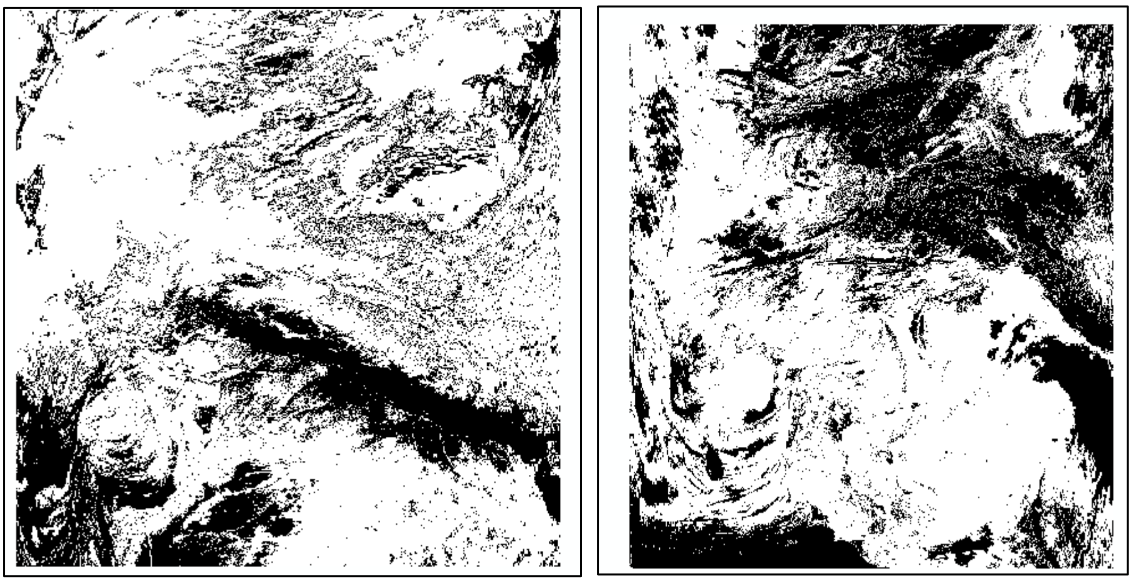
## Zonal Geometry

All the geometric measurements are calculated in order to provide insight into the shape and structure of every zone. The map below illustrates the measurements that have been compiled into the maps.

**Figure 7**

*Map result of zonal geometry*

Image 1 Image 2



## Snow Cover Area and its Socio-Economic Impacts

The socio-economic implications of the Snow Cover Area (SCA) in the Upper Indus Basin (UIB) are among the most important objectives of this study (Joshi et al., 2015). The reduction in snow cover may lead to premature snow melt, which ultimately causes the scarcity of water availability, while the period of agriculture when water resources are significantly required causes a major drop in the crop yield along with the lack of water supply, food insecurity as well as the well being of farmers are affected. Due to the decline in snow cover area, the duration, cycle, and amount of availability of irrigational water, hence the unpredictable yield of crops leads to uncertainties among the farmers, which ultimately affects their well-being. However, this isn't limited to the agriculture sector; it includes other sectors as well, i.e., the tourism industry and the energy sector. The tourism industry, for instance, involves winter sports. The energy sector, i.e., hydroelectric power plants, faces the decline in water flow, which majorly relies on the meltdown of glaciers, besides being affected by the high price of energy, low generation of power as well as disruption in the supply of energy for commercial as well as domestic needs. However, this research will help policymakers adopt the most suitable measures to mitigate the effects of climate change in the Upper Indus Basin (UIB). Similarly, the Upper Indus Basin has a huge tourism industry, and its economic growth majorly relies on the tourism sector; however, winter sports like snow skiing and snow surfing, along with the renting of snow resorts during the winter season, are majorly affected by the snow cover. This causes a burden on the downturn of economic growth in the upper Indus Basin tourism and the drop in revenue.

## Conclusions and Recommendation

The Upper Indus Basin is located at the high-altitude Himalayas and Karakoram Ranges and is of crucial importance when it comes to the assessment of the Snow Cover area (SCA). However, global climate change, i.e., global warming, has an adverse effect on the availability of water resources in Pakistan, whether it is required for agriculture needs, energy power plants, or simply to boost the tourism industry in the Upper Indus Basin (UIB) which is well known for its winter sports activities and winter resorts in specific. This research employed the MODIS data in order to measure the implications of Snow Cover Area (SCA) on water security and livelihood of The Upper Indus Basin (UIB). The comparative analysis of snow cover illustrates a shifting trend in the accumulation period, with a significant anomaly having an influence on the agricultural output, which ultimately affects the livelihood and well-being of farmers, i.e., household income related to the agricultural sector. This research provides insight into the need to adapt water management strategies to align with evolving snow cover dynamics to mitigate potential socio-economic risks. Lately, satellite sensors have been available for this purpose, such as snow mapping and monitoring on scales.

Moreover, any variation and fluctuations in the snow cover area in the Upper Indus Basin (UIB) highlight a number of challenges that require researchers, stakeholders, and policymakers to handle them on an urgent basis. There are a number of adaptive measures and strategies required to sustain economic well-being and boost tourism revenue, agricultural output, and power generation in the Upper Indus Basin. A number of economic challenges have arisen due to the rapid meltdown of glaciers in snow-covered areas in the Upper Indus Basin (UIB), which is mainly due to global warming and overall climate change, as well as pollution. Policymakers need to adopt diversified strategies to help boost investment in this region, as well as support annual tourism activities irrespective of weather variability.

## References

Atif, I., Mahboob, M. A., & Iqbal, J. (2015). Snow Cover Area (SCA) change assessment in 2003 and 2013 using MODIS data of the Upper Indus Basin (UIB), Pakistan. *Journal of Himalayan Earth Sciences*, *48*(2), 117. https://www.proquest.com/docview/1792584561?sourcetype=Scholarly%20Journals

Barnes, W. L., Pagano, T. S., & Salomonson, V. V. (1998). Prelaunch characteristics of the moderate resolution imaging spectroradiometer (MODIS) on EOS-AM1. *IEEE Transactions on Geoscience and Remote Sensing*, *36*(4), 1088-1100. http://dx.doi.org/10.1109/36.700993

Hall, D. K., & Riggs, G. A. (2010). *Normalized-difference snow index (NDSI)*. Encyclopedia of snow, ice, and glaciers. https://www.usgs.gov/landsat-missions/normalized-difference-snow-index

Hasson, S., Lucarini, V., Khan, M. R., Petitta, M., Bolch, T., & Gioli, G. (2014). Early 21st-century snow cover state over the western river basins of the Indus River system. *Hydrology and Earth System Sciences*, *18*(10), 4077-4100. http://dx.doi.org/10.5194/hess-18-4077-2014

Joshi, R., Kumar, K., & ampPalni, L. M. S. (Eds.). (2015). *Dynamics of climate change and water resources of northwestern Himalaya* (Vol. 203). Springer International Publishing.

Joshi, R., Kumar, K., Pandit, J., & amPalni, L. M. S. (2015). *Variations in the seasonal snow cover area (SCA) for Upper Bhagirathi Basin, India. In Dynamics of Climate Change and Water Resources of Northwestern Himalaya* (pp. 9-21). Springer International Publishing.

Justice, C. O., Townshend, J. R. G., Vermote, E. F., Masuoka, E., Wolfe, R. E., Saleous, N., ... & Morisette, J. T. (2002). An overview of MODIS Land data processing and product status. *Remote sensing of Environment*, *83*(1-2), 3-15. http://dx.doi.org/10.1016/S0034-4257(02)00084-6

Negi, H. S., Jassar, H. S., Saravana, G., Thakur, N. K., Snehmani, & Ganju, A. (2013). Snow-cover characteristics using Hyperion data for the Himalayan region. *International journal of remote sensing*, *34*(6), 2140-2161. http://dx.doi.org/10.1080/01431161.2012.742213

Tariq, M. A. U. R., & van de Giesen, N. (2012). Floods and flood management in Pakistan. *Physics and Chemistry of the Earth, Parts A/B/C*, *47-48*, 11–20. https://doi.org/10.1016/j.pce.2011.08.014

Wardlow, B. D., Anderson, M. C., & Verdin, J. P. (2012). *Remote sensing of drought: innovative monitoring approaches*. CRC Press.