INVESTIGATION OF CRYOSPHERE DYNAMICS VARIATIONS IN THE UPPER INDUS BASIN USING REMOTE SENSING AND GIS

J. Iqbal [1], M. Ali [2,*], A. Ali [3], D. Raza [2], F. Bashir [4], F. Ali [5], S. Hussain [2], Z. Afzal [2]

[1] Department of Environmental Engineering, China University of Geosciences, Wuhan, China - jvcomsian@gmail.com
[2] State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University 430079, China - muhammadali.geo1@gmail.com
[3] Institute of Geographical Information Systems, National University of Sciences and Technology, Islamabad, Pakistan
[4] Department of Meteorology, COMSATS University Islamabad (CUI), Pakistan.
[5] Aerospace Information Research Institute, University of Chinese Academy of Science, China.

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ABSTRACT:

Glaciers are storehouses for freshwater. Glaciers Monitoring is one of the most important research areas especially when climate change has been accelerated snowmelt process. The major goal of research was to find snow cover trend for glaciated regions of Pakistan followed by estimation of snow mass balance. The area chosen for it was Upper Indus basin, which includes ranges of Hindukush, Karakoram and Himalayas extended in Pakistan, India and China. This region exhibits high topographic relief and climate change variability. Snow cover trend analysis was performed for eleven years ranging from 2004 to 2014 using Moderate Resolution Imaging Spectroradiometer (MODIS) data imagery product with daily temporal resolution. These results were combined with respective year's average monthly temperature. Further quantitative analysis was performed to relate presence of greater vegetation as an indication of greater snowmelt using Landsat Imagery for these years. Snow mass balance curves reveal that glaciers are regaining their mass balance after losing mass balance in middle of last decade. In addition to that, only freely available data is used for this study. This purpose behind this approach is to prove RS and GIS has an effective and low-cost tool for snow cover monitoring, also mass balance calculations. Continuous monitoring of snow cover dynamics is effective for prediction and mitigation of hazards associated with areas in proximity of glaciated regions. One common hazard is glacial lake outburst phenomenon, which cause severe flash flooding in downstream areas. Year 2004 has the lowest mass snow balance and 2014 has the highest snow mass balance. These different parameters were analysed and results show that snow start melting in months of May and June and faster melting rate observed in months of July and August. With the advancement in computing technologies, it has been easier for computers to handle and manipulate massive datasets. Remote sensing has proved to be an excellent tool for extraction of data from glaciers, snow and oceans for remote areas. In particular, snow cover/snowmelt can tell us continuously changing melting patterns, which helps concerned authorities to take necessary measures for preserving these storehouses of water and to mitigate effect of global warming.

1. INTRODUCTION

The Hindukush, Karakoram, and the Himalayan mountain range accommodate a large number of glaciers and are the major water source for various canals and rivers downstream. The agriculture-based economy of Pakistan is dependent on irrigation water supplied by the Indus River and its sub tributaries. Most of the flow abstracted from the Indus River at Tarbela is contributed by snow and glacier melt of the Karakoram, Himalaya, and Hindukush mountains (Bookhagen and Burbank 2010, Immerzeel, Van Beek et al. 2012, Lutz, Immerzeel et al. 2013). Upper Indus River Bas/.in has a total catchment area of >200,000 km^2 (Bookhagen and Burbank, 2010; Forsythe et al., 2012b; Immerzeel et al., 2009; Tahir et al., 2011a) and almost 12% of the total area (≈22,000 km2) is covered by glacier ice (Hewitt, Gómez Lechón et al. 2007).

It is evident from research that glaciers are retreating at a faster rate in many regions of the world (Wang, Siegert et al. 2013). Similarly, climate change is affecting the glaciated locales of Pakistan. The melting of Hindu Kush-Karakoram- Himalayan glaciers at expediting rate due to global warming will threaten water inflows into Indus River System. Consequently, there is a need for using modern technologies for finding snow cover and snowmelt trends in glaciated regions. Snow mass balance is another important parameter, which can be defined as the gain and loss of ice from the glacier system. Snow mass balance gives us a fair idea of accumulation or ablation of snow (Rundquist and Samson 1980, Qunzhu, Meisheng et al. 1984, Paul 2000, Bolch and Kamp 2005, Paul, Kääb et al. 2007).

The task of monitoring cryosphere dynamics is very challenging. One of the reasons is that most of the glaciers lie in remote mountainous areas and it is very difficult to perform constantly in situ observations and monitoring. Here comes the importance of remote sensing technology. Using remote sensing methods, we can extract data for inaccessible regions where ground surveys cannot be conducted with ease. For example glaciated regions, deserted regions, and hydrological studies particularly oceanography (Tsomaia and Drobishev 1977). In addition, we can extract data like temperature, rainfall, snow cover, and chlorophyll concentration, to mention a few. This kind of data otherwise is recorded on a few ground stations and is interpolated for a large areas. Hence, researchers need to run with a limitation of using approximated values when they use conventional methods other than remote sensing technology.

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* Corresponding author: muhammadali.geo1@gmail.com

Geographic information system offers a possibility of integrating wide range of spatial and non- spatial data sets to perform comprehensive and reliable analysis. (Burrough and MCDONNEL 1998) defined GIS (Geographical Information Systems) as an influential system for spatial data management, storing, recovering, presenting and its assembling to produce results. With the development in modern computing capacities, it has become easier to analyse big datasets. The objective of this research is to find snow cover, area wise and percentage-wise and use of RS (Remote Sensing) methodologies has advantage of availability of very high spatial and temporal resolution datasets. High temporal resolution enables us to perform change detection analysis including snow cover change, build-up area change detection and shoreline change detection. Thus, monitoring changing patterns for any phenomenon has become easier.

We have analysed snow cover for a daily and monthly basis in correlation with temperature. Further, as the availability of irrigation water directly affects vegetation so land cover classification is performed and results are confirmed in correlation with snowmelt. The next step is to calculate snow mass balance and estimation of the quantity of stored water in the form of glaciers.

2. STUDY AREA

The study area includes the upper Indus Basin in northern Pakistan. Upper Indus Basin regions comprise of the ranges of Karakoram and Hindukush. These greatest ranges run from west to east from Northern Pakistan to the Tibet region of China. Some of the prominent areas in this region are Gilgit (35.9202° N, 74.3080° E), Skardu (35.2901° N, 75.6453° E), Jammu and Kashmir (33.7782° N, 76.5762° E), Ladakh of India (34.1526° N, 77.5771° E) and some part of Tibet region of China (Figure 1). The total length of the Himalayan region forms arc of about 2,400 km. In these regions the glacier melting rate is high. Snow and glacier melting from this region fulfil the need for water.

This region exhibits high topographic relief and climate change variability. Due to climate change, the snow mass balance of this glaciated region gets affected. This is a strong motivation to study snow cover trends in this region. The area downstream of the upper Indus Basin is used for land cover classification while the focus on vegetation class. Keeping in view the fact that vegetation changes with the availability of water, land cover classification is compared to the amount of water from snowmelt. This study area includes Muzaffarabad, Bagh, and Mirpur. Azad Jammu and Kashmir (AJK) and Khyber Pakhtunkhwa(KPK) includesBesham, Haripur, Swabi, Nowshera, Mardan, Charsadda, and Peshawar.
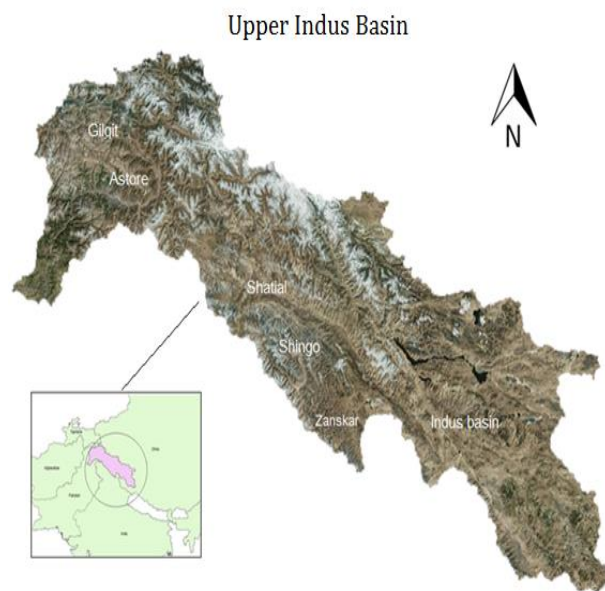

Figure 1: Study Area showing the location of Upper Indus Basin.

3. METHODOLOGY

Landsat daily snow cover data is processed to find daily snow cover in the form of percentage and area. Then monthly averages are calculated. Alongside ERA data is used to find mean monthly temperature(Rango and Martinec 1979). Graphs were made for monthly snow cover and average temperature. Landsat data is used for land cover classification and five classes are made. Snowmelt is calculated from the difference of monthly snow cover. Keeping in view that snow melting is equal to water available for irrigation and domestic use; this was compared with the vegetation class of LULC (Land Use Land Cover) classification(Javid 2014)

3.1 Data Acquisition

The MODIS data was downloaded with the help of pyModis scripts whose reference is available online. Data was downloaded on Linux Ubuntu machine from FTP server which keeps MODIS data. Pymodis has several sub-scripts and modis_download.py is a subscript that is used for downloading data. For Landsat data, an area of interest chosen is a large area comprising of three mountain ranges, so five scenes of Landsat were overlapping the area. Data was downloaded from USGS Earth Explorer. Table 1 shows the Paths and Rows of the Landsat data series for the study area.

Scenes	Paths	Rows
LE71490352005108PFS00	149	035
LE71490362005108PFS00	149	036
LE71500352005179EDC00	150	035
LE71500362005131EDC00	150	036

LE71510362005154EDC00	151	036

Table 1: Scenes of Landsat data used

3.2 Pre-processing

MODIS data comes in HDF-EOS format. It stands for Hierarchal Data Format – Earth Observing System. It is the standard format for all NASA Earth observing system data products. Also, MODIS data is always provided in a sinusoidal map projection. So, there are two things that need to be catered. One is a conversion of format so that ArcMap and other GIS software can handle data. Second is the re-projection of data to local or global best-suited datum. MODIS Re-projection Tool (MRT) was used for the conversion of data to tiff format and WGS-84 Geographic datum. MRT can read data in HDF-EOS format; can perform a geographic transformation to a different coordinate system/ cartographic projection. It writes the output to file formats other than HDF-EOS. MRT is freely available from LP DAAC.

Batch processing was done by generating parameter files for the whole year and running year-wise batch process of mosaicking, format conversion, and projection transformation. Data were converted to tiff format. Snow cover, snow albedo, fractional snow cover, and Quality Assessment (QA) tiles are produced from compressed MOD10A1 once it got decompressed.

Classification
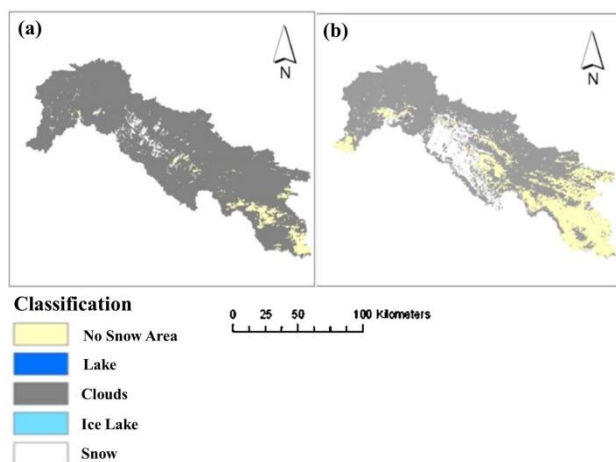- No Snow Area
- Lake
- Clouds
- Ice Lake
- Snow

Figure 2: (a) Land Classification Map before Pre-processing and (b) Land Classification Map after Pre-processing

A python script was used for the extraction of converted data according to the area of interest. After this step, the size of data gets reduced which helps in further processing. The temporal filter technique was applied to minimize the cloud cover. This technique uses one image of the previous day and one image of the next day. It replaces cloudy pixels of current day image with non-cloud pixels found in either previous or next day image. Figure 2a shows the study map before applying this technique and Figure 2b represents after pre-processing technique which clearly consists of less amount of cloud cover. Landsat 7 data is affected by scan line error, so ENVI Gapfill extension was used for filling scan lines using triangulation algorithm (Gratton, Howarth et al. 1990) .

4. RESULTS

Supervised classification technique was used to classify all 5 classes for every year in the range (2004-2014). Figure 3a shows supervised classification for the year 2005 and Figure 3b shows supervise classification for the year 2007. Classification was done in ENVI by providing training data for 5 classes as vegetation, water bodies, snow, cloud, and barren land. Special care was taken in choosing training data by using ArcGIS base maps and Google Earth as reference. In particular, classification of vegetation class is done with greater accuracy (Gratton, Howarth et al. 1990, Bishop, Bush et al. 2014).

Year	Vegetation Square Km	Snow Melted Square Km
2005	13515.17	102878.22
2007	6336.52	84134.98
2009	24688.7	50565.15

Table 2: Comparison of Vegetation and Snowmelt

Table 2 shows that in years when there is greater snowmelt, excess water is available for irrigation; hence there is large area under vegetation cover. Moreover, contrary to this, when there is less snowmelt, like snow melted from around 50565.15 km^2 area, then there is less vegetation of 24688.7 km^2.

Value
- Water
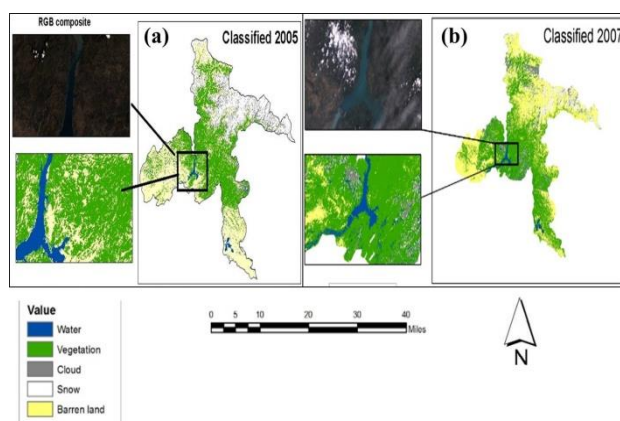- Vegetation
- Cloud
- Snow
- Barren land

Figure 3: (a) Land Cover Classification Map of 2005 and (b) Land Cover Classification Map of 2007.

We got almost a similar trend for all eleven years (2004-2014). Snow covers decrease with increase in temperature in June, July and August. Snow cover seems to be recovered in winter season with the start of snowfall. A slide increase in temperature is in 2004 with a small decrease of snow area and large percentage of snow cover is in 2012-13 during extreme low temperature season.

The annual and seasonal snow cover analysis shows that its shift in the ice cover has a strong inhibitory effect with summer average conditions of the catchment, resulting in a significant volume of river flow to predict the peak summer flow. It's also very necessary to track the ice and snow concentrations at high elevation, as the change can be seen by statistics. Sun and wind speed magnitude are two key snowmelt controlling elements,

another significant thing is air temperature as the difference depends on the surface air among ice and rain. The declining pattern in the observed average temperature helps processing snow cover area in two ways, a drop in normal temperature that the snowmelt process is slowdown. While an increase in snow cover reduces the local temperature as snow reflects most of the incoming solar radiation causing a cooling effect.

Figure 4 shows temperature and the corresponding snow melt percentage monthly for the year 2004. It can be observed that for July and August, snow cover percentage is lowest. Similar results were extracted for other 10 years too. The trend was almost similar like for the year 2004. The results from Table 3 and Table 4 show that in years when there is greater snowmelt, excess water is available for irrigation; hence there is large area under vegetation cover. Moreover, contrary to this, when there is less snowmelt, like snow melted from around area of 50565.15 km^2, then there is less vegetation of 24688.7 km^2.
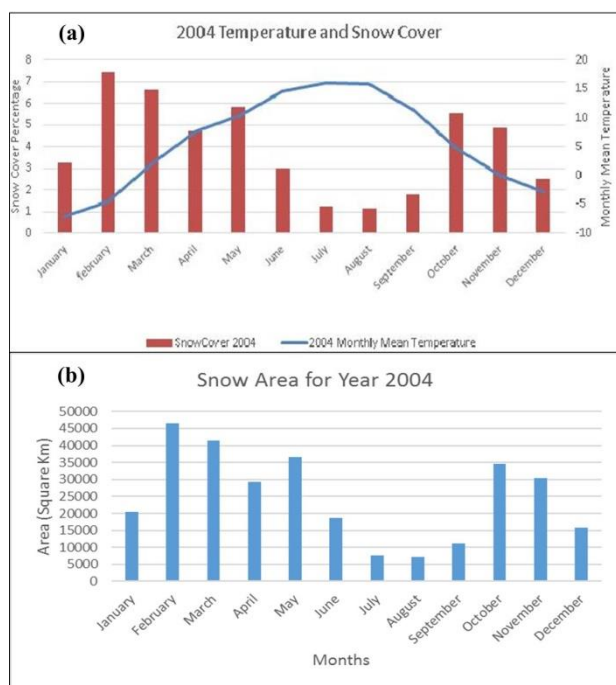

Figure 4: (a) Snow Area for year 2004 and (b) Comparison of Temperature and Snow Cover for year 2004

Snow mass balance is calculated by using snow depth and snow density from ERA Interim data. These parameters are multiplied with area of snow to find snow mass balance.

Months	Mass Metric Ton	Water Metric Ton
January	671929351.6	134385870.3
February	1751766224	350353244.8
March	1617588445	323517688.9
April	1189222665	237844533.1

Table 3: An overview of snow mass balance calculations for year 2004

Estimation of fresh water reserve is very important analysis conducted as a part of this research. This was achieved by combining prior knowledge of amount of water produced from specific melt down of snow mass. If we know that 10 metric ton of snow produces two metric ton of water, we can estimate amount of water that is stored in the form of snow.

Year	Month	Density kg/m^3	Mass Metric Ton
2004	January	139.873138	671929351
2004	February	160.1102951	1751766224
2004	March	160.0961355	1617588445
2004	April	174.977112	1189222665
2004	May	130.8899327	1135912070

Table 4: Estimate of Water reserve from snow mass balance for year 2004

5. CONCLUSION

RS & GIS is an efficient and cost-effective tool for estimating and evaluating spatial-temporal changes using multi-temporal satellite imagery. Availability of the historic data having minimum errors and being free of clouds are of prime importance in the evaluation and estimation of temporal changes and establish the relationship between different land phenomena's. Climate change would usually have detrimental consequences on the cryosphere. The current analysis also showed that there is a widespread loss of snow and glacier. Global temperature change improves the atmosphere's ability to absorb more humidity. This precipitation is then transported to numerous locations, Moisture is borne from the Mediterranean and Black and Caspian Sea spread to GB by western airflow and monsoonal storms moving to the higher altitude.

The study has shown a very sharp view of the temperature variations in snow-covered areas. Snow and glacier melt, however, dominates the flow of the Indus River and more investigation is required to absorb glaciers in each mountainous region.

The higher spatial resolution also increases the accuracy and reliability of the analysis. Upper Indus Basin regions comprise of the ranges of Karakoram and Hindukush. These greatest ranges run from west to east from Northern Pakistan to the Tibet region of China. Supervised classification technique was used to classify all 5 classes for every year in the range (2004-2014).Classification was done in ENVI by providing training data for 5 classes as vegetation, water bodies, snow, cloud and barren land. Snow mass balance curves reveal that glaciers are regaining their mass balance after losing mass balance in middle of last decade. We got almost similar trend for all eleven years (2004-2014). Snow covers decrease with increase in temperature in June, July and August. Snow cover seems to be

recovered in winter season with the start of snowfall. It can be observed that for July and August, snow cover percentage is lowest. Similar results were extracted for other 10 years too. A slide increase in temperature is in 2004 with a small decrease of snow area and large percentage of snow cover is in 2012-13 during extreme low temperature season. In addition to that, only freely available data is used for this study. This purpose behind this approach is to prove RS and GIS has an effective and low-cost tool for snow cover monitoring, also mass balance calculations. Continuous monitoring of snow cover dynamics is effective for prediction and mitigation of hazards associated with areas in proximity of glaciated regions. One common hazard is glacial lake outburst phenomenon, which cause severe flash flooding in downstream areas. In particular, snow cover/snowmelt can tell us continuously changing melting patterns, which helps concerned authorities to take necessary measures for preserving these storehouses of water and to mitigate effect of global warming.

6. ACKNOWLEDGMENT

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