INVESTIGATION OF SPATIAL AND TEMPORAL VARIATIONS OF CRYOSPHERE DYNAMICS OVER THE ASIAN WATER TOWER USING GIS AND REMOTE SENSING

FINAL YEAR PROJECT UG 2012

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This is to certify that the

Final Year Project Titled

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Has been accepted towards the requirements

for the undergraduate degree

in

GEO-INFORMATICS ENGINEERING

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DEDICATION

We dedicate this to our parents and teachers whose affection, love, encouragement and prayers have enabled us to succeed in our ambitions. They taught us the value of perseverance and hard work, teaching us that every success and failure brings us closer to being the best version of ourselves.

ABSTRACT

Glaciers are fresh water storehouses. Ever since climate change has accelerated the snowmelt process, research focused on monitoring glaciers has emerged as a significant research domain. One of the major goals of this research was to identify snow cover trends for glaciated regions of Pakistan and provide estimations of snow mass balance. The area chosen for this study was the Upper Indus basin, which includes the mountain ranges of Hindu Kush, Karakoram and the Himalayas. This region exhibits high topographic relief and climate change variability. Snow cover trend analysis for this region was performed for eleven years ranging from 2004 to 2014 using MODIS imagery with daily temporal resolution. Results were then compared with each year's average monthly temperature. Further quantitative analysis was also performed to evaluate whether presence of increased vegetation is a reliable indicator of greater snowmelt. Snow mass balance is an important parameter to estimate the accumulation or ablation of glaciers. Snow mass balance of four selected years was calculated and compared. Year 2004 had the lowest mass snow balance while 2014 had the highest snow balance. Analysis of different parameters concluded that snow generally starts melting in the months of May, June and continues melting at faster rates in the months of July and August. With the arrival of winter and subsequent snowfalls, glaciers regain their mass. With the advancement in computing technologies, it has become easier for computers to handle and manipulate massive datasets. Remote sensing has proved to be an excellent tool for data collection from remote areas. Analysis of snow mass balance has revealed that glaciers in the Hindu Kush and Himalayan ranges are regaining their mass. Finally, a web interface was programmed to share research results with GIS and non-GIS users. This should increase awareness about applications of GIS and RS technology.

ACKNOWLEDGEMENTS

We are grateful to Allah Almighty for our good health and well-being. Foremost, we would like to express our most sincere gratitude to our supervisor Dr. Muhammad Azmat. We feel extremely fortunate to have had the opportunity to work alongside such a great mentor. While he gave us the freedom to work on our own, he was always available to provide guidance whenever our steps faltered. Without his support and trust in our abilities, we would never have been able to attain this milestone.

We would also like to thank our classmates who supported us during the difficult times and made our graduate experience that much more enjoyable. We are thankful for their constructive criticism, advice and friendship throughout this journey.

We would also like to take this opportunity to acknowledge the efforts of IT staff IGIS for providing us with all the necessary technical support. The computer systems were always well maintained, hard drives were available for our data backups and adequate malware protection removed any worries of data loss or theft. Their patient help and guidance with software installations was extremely useful.

Above all, we are grateful to our parents, whose love and prayers are the driving force behind all our successes. In times of despair, their continued encouragement pushed us not to give up. We appreciate the many sacrifices they have made on our behalf and are grateful for their generous presence in our lives. This dissertation is a testament to their endless support and love.

Muhammad Kamran

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LIST OF ABBREVIATIONS

1	MODIS	Moderate Resolution Imaging Spectrometer
2	GIS	Geographical Information System
3	RS	Remote Sensing
4	LULC	Land Use Land Cover
5	MRT	MODIS Re-projection Tool
6	NDSI	Normalized Difference Snow Index

CHAPTER 1

INTRODUCTION

The many glaciers in the Hindu Kush, Karakoram and Himalayan mountain ranges are a major water source for most canals and rivers in downstream Pakistan. The agriculture-based economy of Pakistan is dependent on irrigation water supplied by the Indus River and its sub tributaries. Majority of the flow abstracted from the Indus River at Tarbela is comprised of the snow and glacier melt of the Karakoram, Himalaya and Hindu Kush mountains (Bookhagen and Burbank, 2010; Immerzeel et al., 2012, 2013). Upper Indus River Basin 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 km^2) is covered by glacier ice (Hewitt, 2001; Hewitt, 2007).

Research shows that similar to many other regions of the world, glaciers in Pakistan are retreating at an increasingly faster rate due climate change. The melting of Hindu Kush-Karakoram-Himalayan glaciers at expedited rates due to global warming threatens water inflows into the Indus River System. The critical dependency means there is an increased need to promote the use of modern technologies in Pakistan to study snow cover and snowmelt trends in glaciated regions. Snow mass balance, which is simply the gain or loss of ice from glacier systems, is another important parameter that needs study. This measure gives researchers a fair idea of accumulation or ablation of snow.

The task of monitoring cryosphere dynamics is very challenging, in large part due to the difficulty of performing constant in situ observations and monitoring in remote mountainous areas where the majority of glaciers are located. This is where remote sensing technology can be extremely valuable. Remote sensing methods allow data extraction for regions that may be inaccessible or where ground surveys are difficult to conduct. Examples of such areas could be glaciated regions, deserts or even the deep ocean for hydrological studies and oceanography. Remote sensing allows the extraction of data such as temperature, rainfall, snow cover, chlorophyll concentration, etc. Conventional methods of extraction for this type of data involve recording data at only a few ground stations and then interpolated for large areas. Hence, research using the traditional approach suffers from the limitations caused by using only approximated values. Moreover, RS methodologies offer the use of very high spatial and temporal resolution datasets. High temporal resolution enables us to perform change detection analysis such as snow cover, build up area and shoreline change detection. This makes monitoring changing patterns for any phenomenon much easier.

Geographic information systems offer the possibility of integrating a wide range of spatial and non-spatial data sets to perform comprehensive and reliable analysis. Burrough and McDonnel (1998) defined GIS as an influential system for spatial data management, storage, recovery, presentation and assembly to compile results. With the development in modern computing capacities, it has become easier to analyze big datasets.

In this research, we have analyzed snow cover for daily and monthly basis in correlation with temperature. Furthermore, since availability of irrigation water directly affects vegetation, we also performed land cover classification by comparing results with snow melt data. In this stage, we calculated snow mass balance and provided estimates of stored water quantities in glacier form. Finally, a web interface was constructed to share our research findings with GIS and non-GIS users for easy access, comparison and analysis.

1.1 Objectives

According to methodology used, snow cover mapping is an important step before calculating snow mass balance. This research has emphasized on the following objectives:

i. To find snow cover, both area and percentage wise.
ii. To map land-cover dynamics, with particular focus on variations in vegetation
iii. To calculate snow mass balance
iv. Web interface for easy sharing of results

CHAPTER 2

LITERATURE REVIEW

A glacier is a slowly moving mass of ice formed by the accumulation and compaction of snow on mountains. Glacier melting is a natural process and occurs due to seasonal temperature changes. However, glaciers may melt at a faster rate if temperatures rise.

2.1 Introduction

According to Rasul et al. (2010) Glaciers and icy surfaces are serious indicators of climate change variations and global warming. Changes in the glacial length, areal extent or mass balance are all indicators of climate change in a region where climate change signal is not clear. Various inferences regarding glaciers and their behavior as indicators of climate change have been stated in the past but they all lead to the common conclusion that rising temperatures due to climate change and global warming are causing glaciers to melt faster.

2.2 Behavior of Glaciers

Glaciers, all around the world are retreating at a faster rate. The interaction of atmosphere-cryosphere approach is therefore appropriate to study the dynamic behavior of glacial fluctuations. Melting of glaciers due to rising temperatures also contributes to the process of upward shifting of the snow line and consequently, the upward migration of plant and animal species. The rampant effects of global warming are more obvious in glaciated regions than in any other parts of the world due to the steadily shrinking size of mountain glaciers, reduced snow cover duration and rise in formation of glacial lakes and glacial lake outburst floods (Rasul, 2010). Availability of satellite data has made such studies of glaciers a possibility.

2.3 Snow Mass Balance

Snow mass balance is the gain and loss of ice from glacier systems. Snow mass balance may be defined as the 'health' of a glacier. A glacier losing more mass than gaining will result in negative mass balance while a glacier gaining more mass than losing will result in a positive mass balance. There are three methods to calculate snow mass balance; conventional method, geodetic method and hydrological method.

2.3.1 Conventional method

In the accumulation area, thickness and density of snow is usually investigated in cores or pits. Ablation of ice is determined by means of stakes, assuming an ice density of around 900 kgm–3. In regions with very deep snow, accumulation is also sometimes measured using stakes (Hagg, 2004).

2.3.2 Geodetic method

The geodetic method is based on comparison of accurate topographic maps and determination of volume change for the period between photogrammetric surveys. Mean densities of firn and ice help in deriving water equivalent (Hagg, 2004).

2.3.3 Hydrological method

The hydrological method calculates glacier mass balance as a storage term in the water balance. Subtraction of runoff and evapotranspiration from precipitation delivers the glacier mass budget for the whole catchment area. Volume change may be calculated by multiplying snow depth with snow area. For our project, we acquired densities (Kg/m^3) and depth (meters) from ERA Interim, Monthly means of Daily means (Hagg, 2004).

2.4 Glaciers Area Coverage

To its north, Pakistan hosts three world famous mountain ranges i.e. Himalayas, Karakoram and Hindu Kush. These contain more than 5000 glaciers feeding the Indus from 10 sub-basins through different tributaries (Berthier, 2007). Pakistan's glaciers are spread over an area of about 16933 Km. Pakistan is home to 108 peaks above 6000m, and numerous peaks above 5000m and 4000m. The HKKH is an ensemble of mountain ranges stretching east to west over 2000km, containing around 60,000 km2 of glaciers (Kaab, 2012).

CHAPTER 3

MATERIALS AND METHODS

This chapter gives an overview of the study area and the materials and techniques used to undertake this research.

3.1 Study Area

Our study area encompasses regions in the upper Indus Basin, located in northern Pakistan. Upper Indus Basin regions comprise of the Karakoram and Hindu Kush mountain ranges. These great 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) , Leh of India (34.1526° N, 77.5771° E) and some part of Tibet region of China. The entire Himalayan region forms an arc of about 2400 km. Glacier melting rate in these regions is high, fulfilling water requirements of the local community. This region exhibits high topographic relief and climate change variability. Due to climate change, snow mass balance of this glaciated region has been affected negatively. This provides a strong motivation to study snow cover trends in the region.

The area downstream of the upper Indus Basin is used for land cover classification with a focus on vegetation classification. Keeping in view that vegetation changes with availability of water, land cover classification was compared to the amount of water from snowmelt. The study area consists of two major regions:

3.1.1 Azad Jammu and Kashmir (AJK)

Area under the region Azad Jammu and Kashmir of includes Muzaffarabad, Bagh and Mirpur.

3.1.2 Khyber Pakhtunkhwa

Khyber Pakhtunkhwa includes Besham, Haripur, Swabi, Nowshera, Mardan, Charsadda and Peshawar.

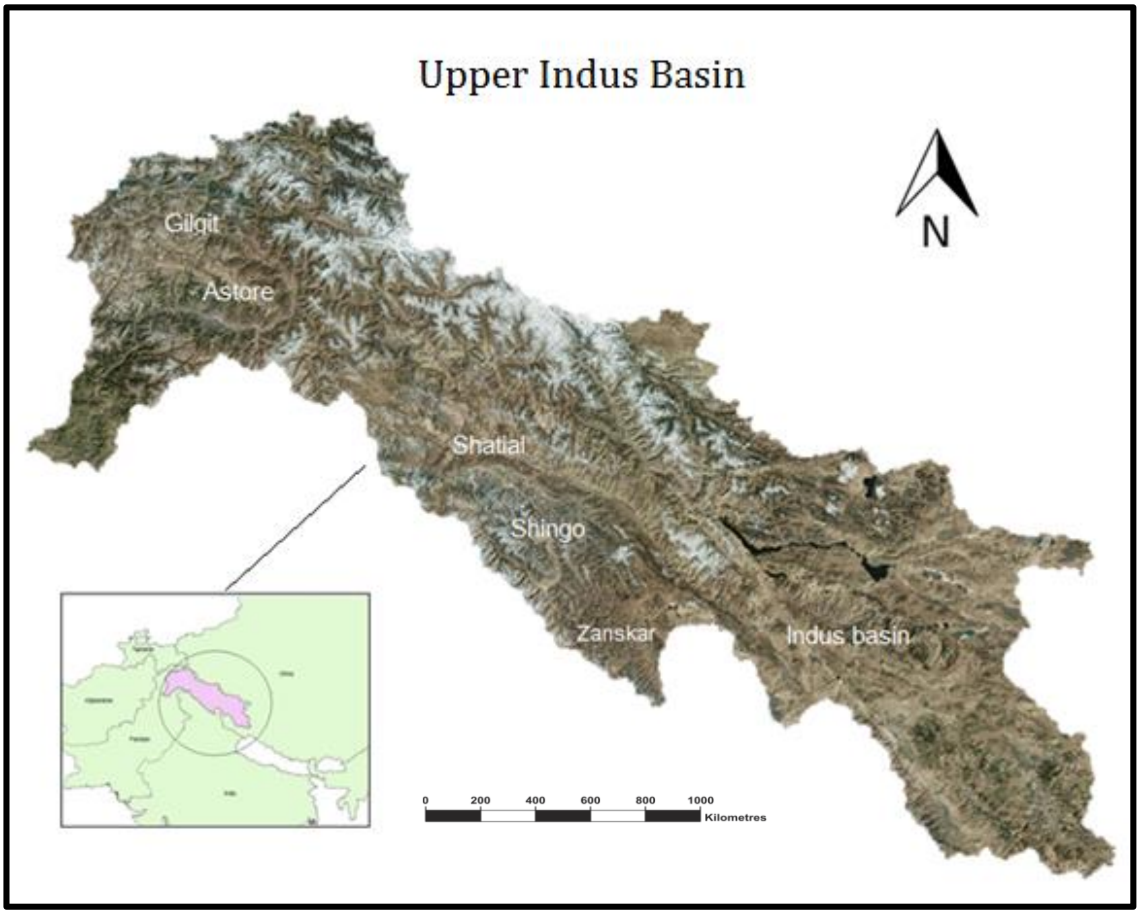


Figure 1: Study area, Upper Indus Basin

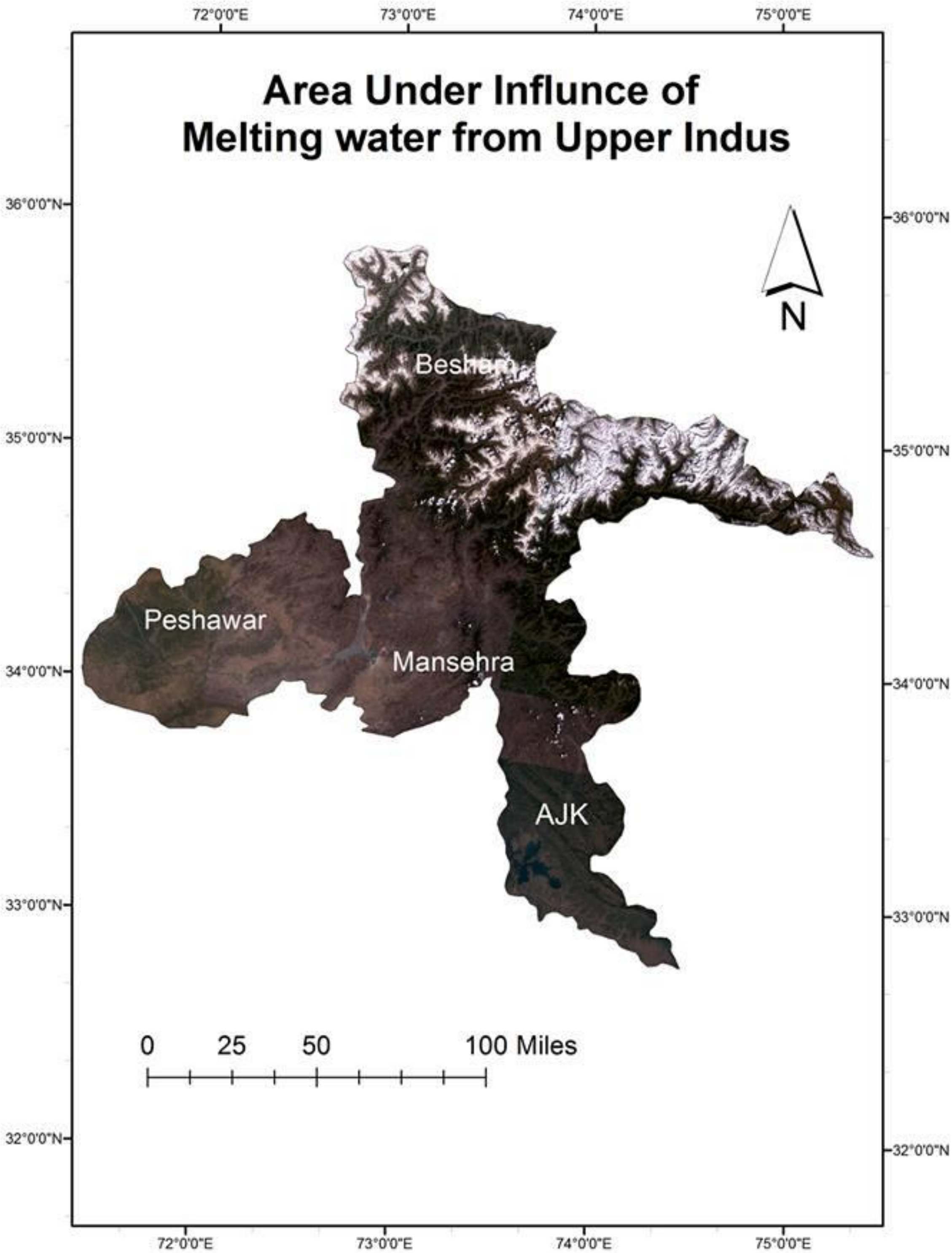


Figure 2: Study area for land cover classification

3.1.3 Climate

The Upper Indus area experiences temperature variations from one region to another, with a high likelihood of severe weather conditions. Much of the variations in temperature are an effect of the surrounding mountains. In some regions, temperatures often fall below zero. However, in other regions, like Gilgit, temperatures may rise up to 35°C in June and July. Most of the regions face snow falls during winter season and snow melt during the summer.

3.1.4 Glaciers

This region is home to around 5,218 glaciers. These glaciers serve as the natural regulator for water distribution to the whole of Pakistan. They feed most of the country''s rivers including the Indus River, which is the major source of fresh water for the entire country. This part of the world is often referred to as the most heavily glaciated region outside of the Polar Region. One of the largest glaciers here is the Siachen Glacier, which has length of approximately 70 km and is the second largest glacier in the world. Biafo Glacier is the third largest glacier with a length of about 63 km. Other glaciers in this region include Baltoro Glaciers (62 km), Hisper Glaciers (53 Km), Batura Glciers (58 km), Rimo Glaciers (45 Km), Chogo-Lunga (47 Km), Panma Glaciers (44 Km), Saropo-Laggo Glaciers (33 Km) and Khurdopin Glaciers (41 km).

3.1.5 Physiography

Northern Pakistan has one of the highest mountain ranges in the world. This is a region of high topography where the land is very sloppy. Three large ranges in the region are the Himalayan, Hindu Kush and Karakoram mountains. One of the highest peaks in this range is the Nanga Parbat, having a height of about 8,126 m. The Karakoram Mountains have an average height of about 6000m. The highest peak within these ranges is the mighty K-2, the world's second highest mountain, rising to a height of 8,610m. Due to steep slopes, water from the upper parts of mountains flows very quickly to the lower regions.

3.2 Dataset Used

High temporal resolution data is the requirement for finding change across any phenomenon.

3.2.1 Satellite Images

Datasets from Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat 7 have been used in this research study. The reason behind choosing MODIS data is its very high temporal resolution. MOD10A1 data set contains **daily**, gridded snow cover, albedo and quality assurance band. MODIS data has 500 m by 500 m spatial resolution. The snow cover was identified using Normalized Difference Snow Index (NDSI).

Normalized-Difference Snow Index (NDSI) is the normalized difference of two bands (one in visible and one in near infrared or short wave infrared parts of the spectrum). Snow is highly reflective in the visible part of the spectrum and while being absorbent in the near infrared or short wave infrared region of the spectrum. Clouds are distinct from snow based on the high reflectance of clouds in the same region of the spectrum.

Additional data set of ERA Interim daily was used for analyzing temperature trends, finding snow depth and snow density. Landsat 7 imagery was used for land cover classification.

3.2.2 Methodology Overview

Landsat daily snow cover data was processed to find daily snow cover in percentage and area. Monthly averages are then calculated. ERA data was also processed alongside the Landsat cover data to find mean monthly temperatures. Graphs were then generated for monthly snow cover and average temperature representation.

Landsat data was used for land-cover classification and five classes were made. Snow melt was calculated by estimating difference in monthly snow covers. Keeping in view that snow melt translates to water available for irrigation and domestic use, snow melt calculations were subsequently compared with the vegetation class of LULC classification.

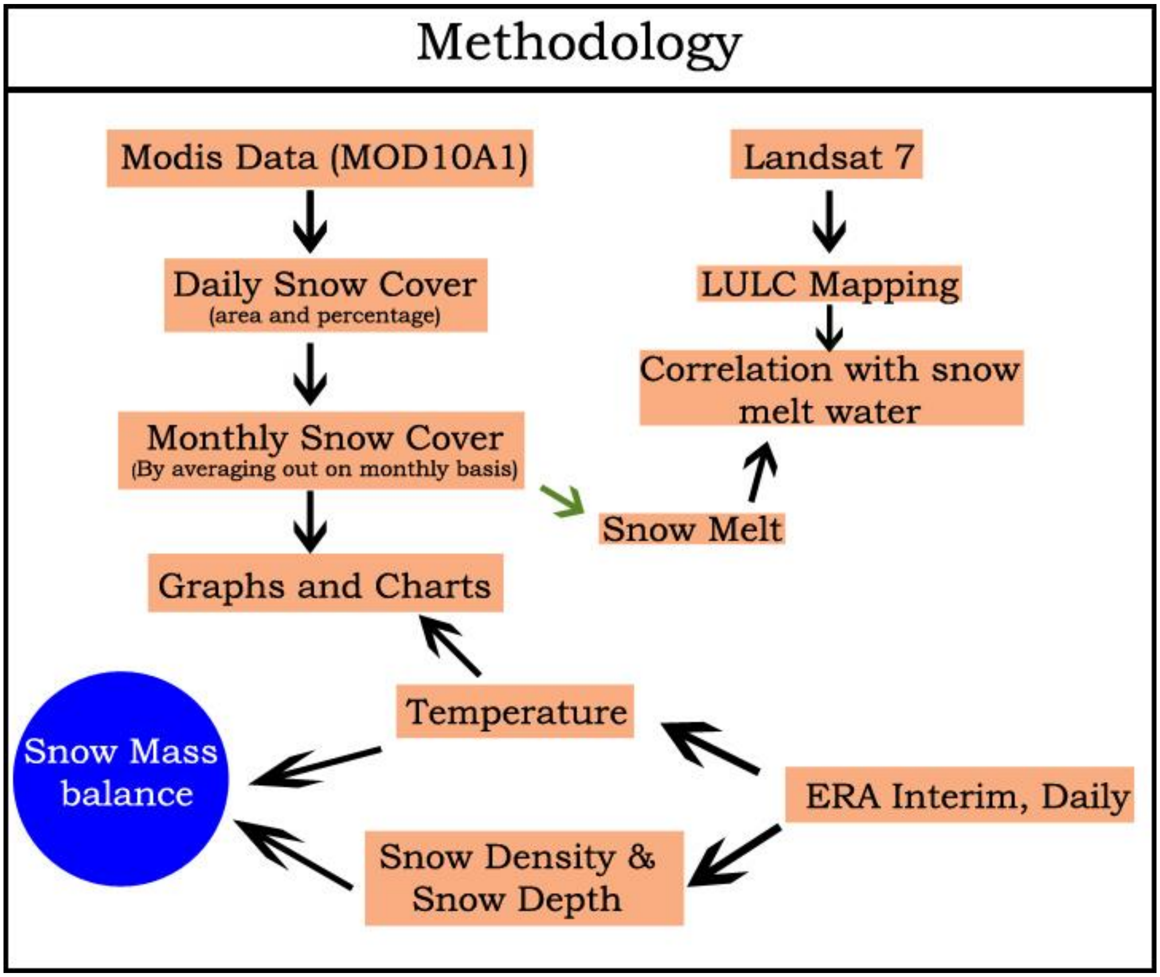


Figure 3: Methodology Overview

3.2.3 Working on MODIS data

Following are detailed steps from acquisition to final processing of MODIS data.

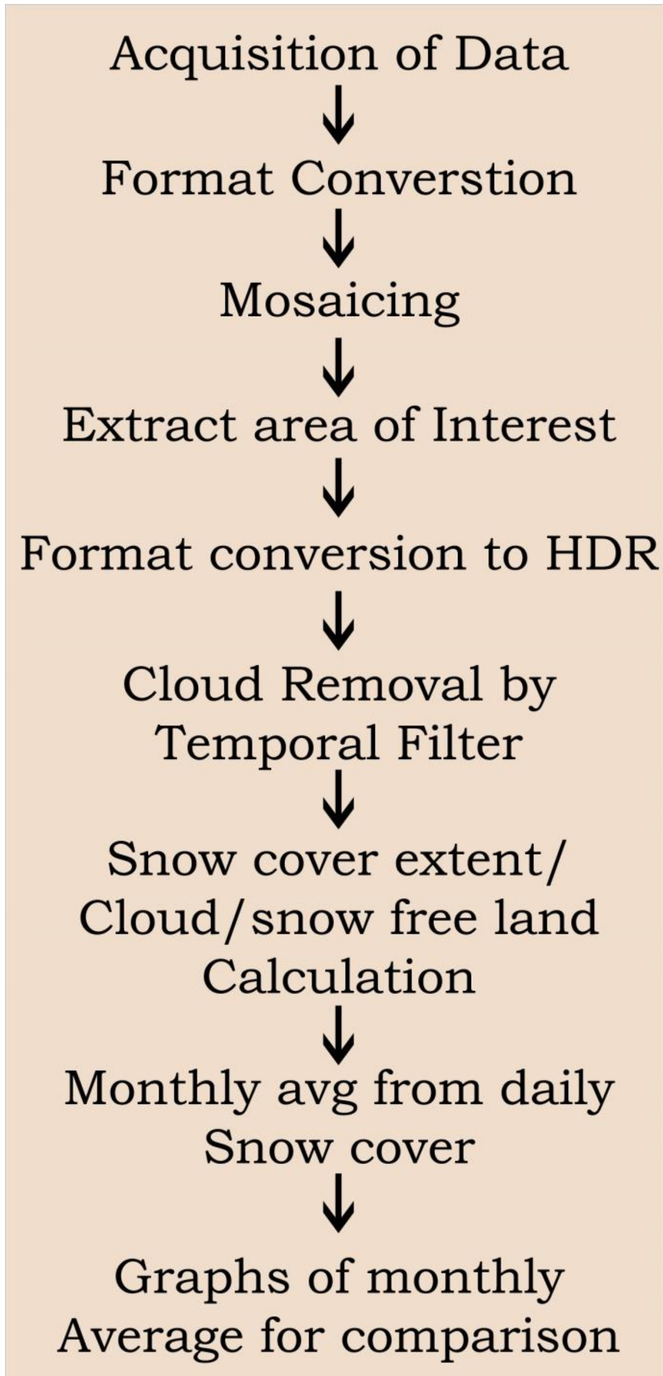


Figure 4: MODIS Data processing workflow

3.2.3.1 Data Acquisition

The data was downloaded with the help of pyModis scripts whose reference is available online.

Website Reference: http://pymodis.org/

Data was downloaded on Linux Ubuntu machine from the FTP server storing MODIS data. Given below is a snapshot of the modis_download.py script and its downloading process. Pymodis has several sub-scripts and modis_download.py is a sub script used for data downloads.

Some key references are:

-u URL to ftp server

-s Sub directory of FTP server keeping data

-p Product of Modis data

-j If –j is included in script, it will download the preview jpg files as well

-f –e are from and end dates

This gives the path to the destination folder where downloaded files are to be stored.

3.2.3.2 Format Conversion

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 products. MODIS data is always presented in sinusoidal map projection form. Therefore, before we could utilize the data for our research, we needed to convert the data into our required formats so that ArcMap and other GIS software could process it. Secondly, data needed re-projecting to local or global best-suited datum.

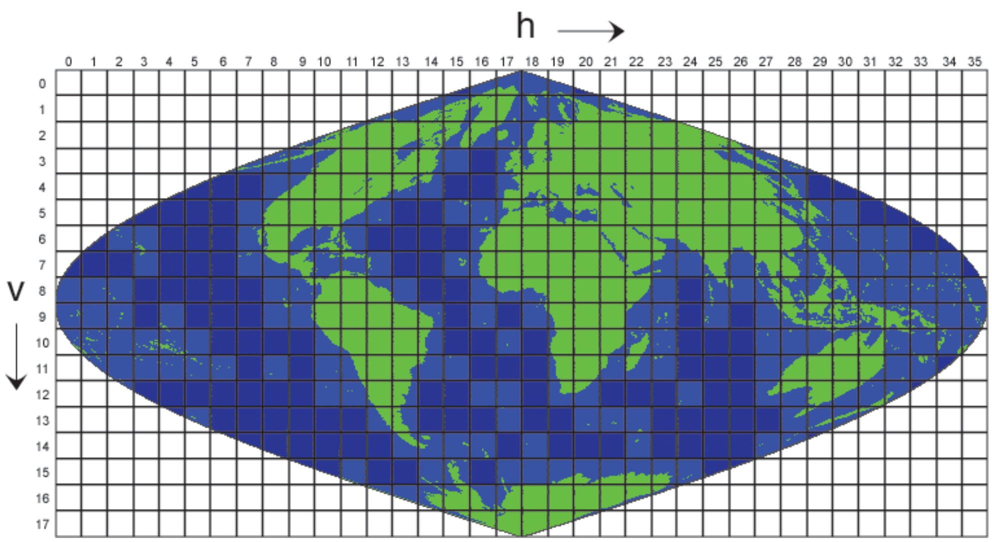


Figure 5: Sinusoidal Grid of Path and Rows of MODIS

3.2.3.3 Modis Re-projection Tool (MRT)

The MODIS Reprojection Tool was used for conversion of data to tiff format and WGS-84 Geographic datum. MRT has the ability to read data in HDF-EOS format, perform geographic transformations to a different coordinate system/cartographic projection as well as write the output to file formats other than HDF-EOS. It is freely available from LP DAAC.

Reference website: https://lpdaac.usgs.gov/tools/modis_reprojection_tool

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. As our area of interest comprises of two Modis tiles, h23v05 and h24v05, mosaicking needed to be performed before the rest of the data processing. Data was initially converted to tiff format. Decompressing the compressed MOD10A1 produced snow cover, snow albedo, fractional snow cover and Quality Assessment (QA) tiles.

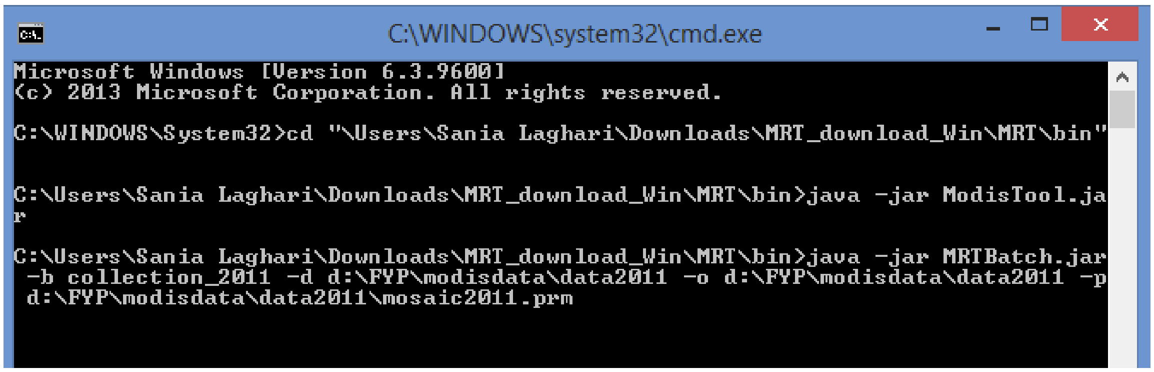


Figure 6: MRT Batch processing environment

Some of key references are

-b batch file name (to be created)

-d directory where data lies

-o output directory

-p reference perimeter file (.prm format)

3.2.3.4 Extraction according to Area of Interest

Python scripts were used for extraction of converted data according to area of interest shapefile. The section “About Area” of this document describes the area of interest in detail. This reduces the step size of data and helps in further processing.

```
import arcpy, os
from arcpy import env
from arcpy.sa import *
```

```
env.workspace                                                     =
"D:/study_material/MODIS_data/data2008/tiffs"
arcpy.CheckOutExtension('Spatial')



output = "D:/study_material/MODIS_data/data2008extracted"
mask                                                              =
"D:/study_material/MODIS_data/mask/area_indus_tarbela.shp"
#files = arcpy.ListFiles("*.tif")

rasterlist = arcpy.ListDatasets("*", "Raster")
for i in rasterlist:
    print i
    outExtractByMask = ExtractByMask(i, mask)
    i = i[:-4]
    print i
    bcd = int(i)
    if (bcd < 100):
        i= "0" + str(bcd)
    if (bcd < 10):
        i= "00" + str(bcd)

    outname = output + "as_" + i + ".tif"
    print "Processing: " + outname
            #os.path.join(outws, str(i)) # Create the full
out path
    outExtractByMask.save(outname)

print "=================DONE======================="
arcpy.CheckInExtension('Spatial')
```

3.2.3.5 Format Conversion to HDR

This conversion was necessary before taking data as input in MODIS snow tool.

3.2.3.6 Cloud cover removal

Temporal filter technique was applied to minimize cloud cover. This technique uses one image of previous day and one image of next day. It replaces cloudy pixels of current day image with non-cloud pixels found in either the previous or next day image.

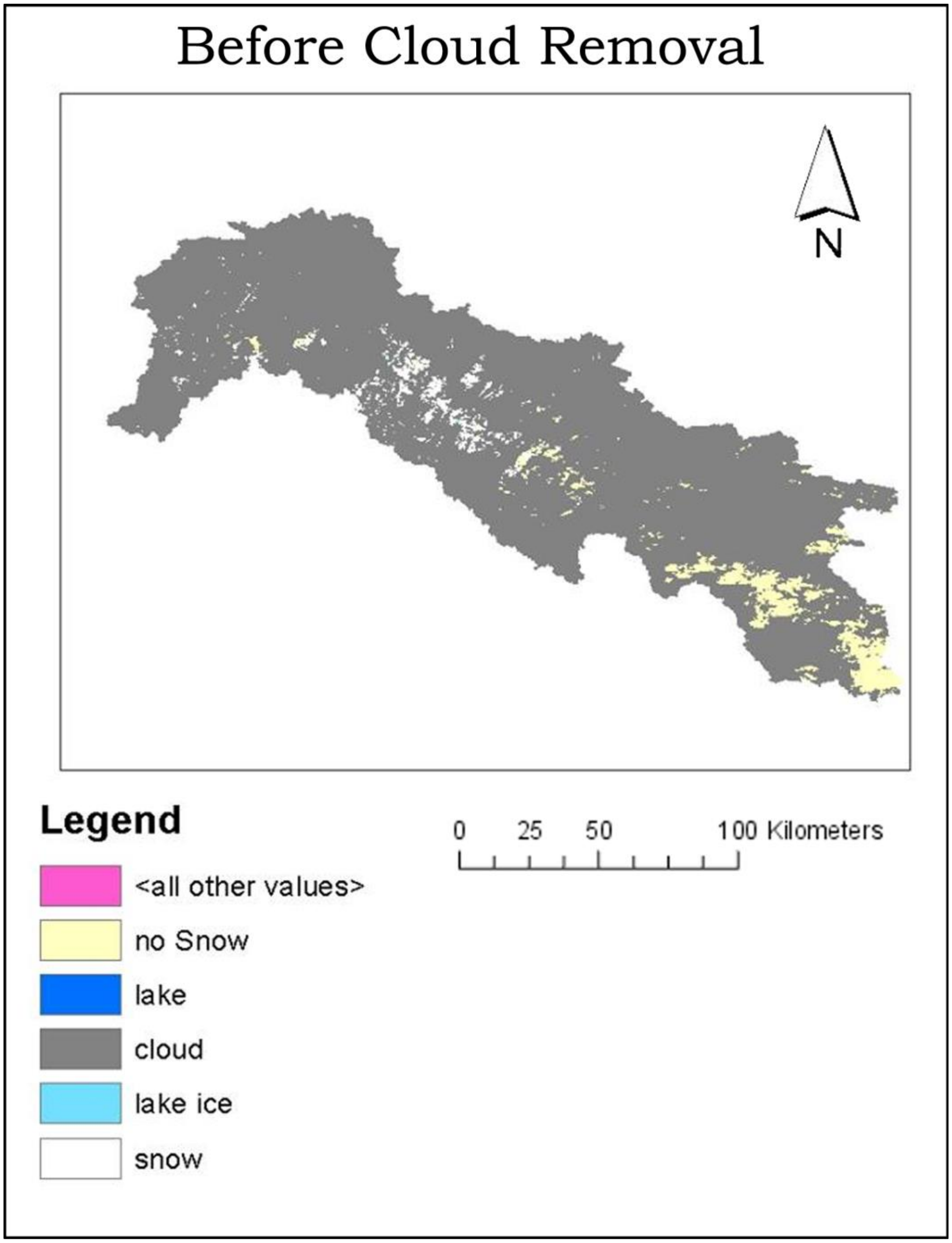


Figure 7: MOD10A1 Imagery before Cloud Removal

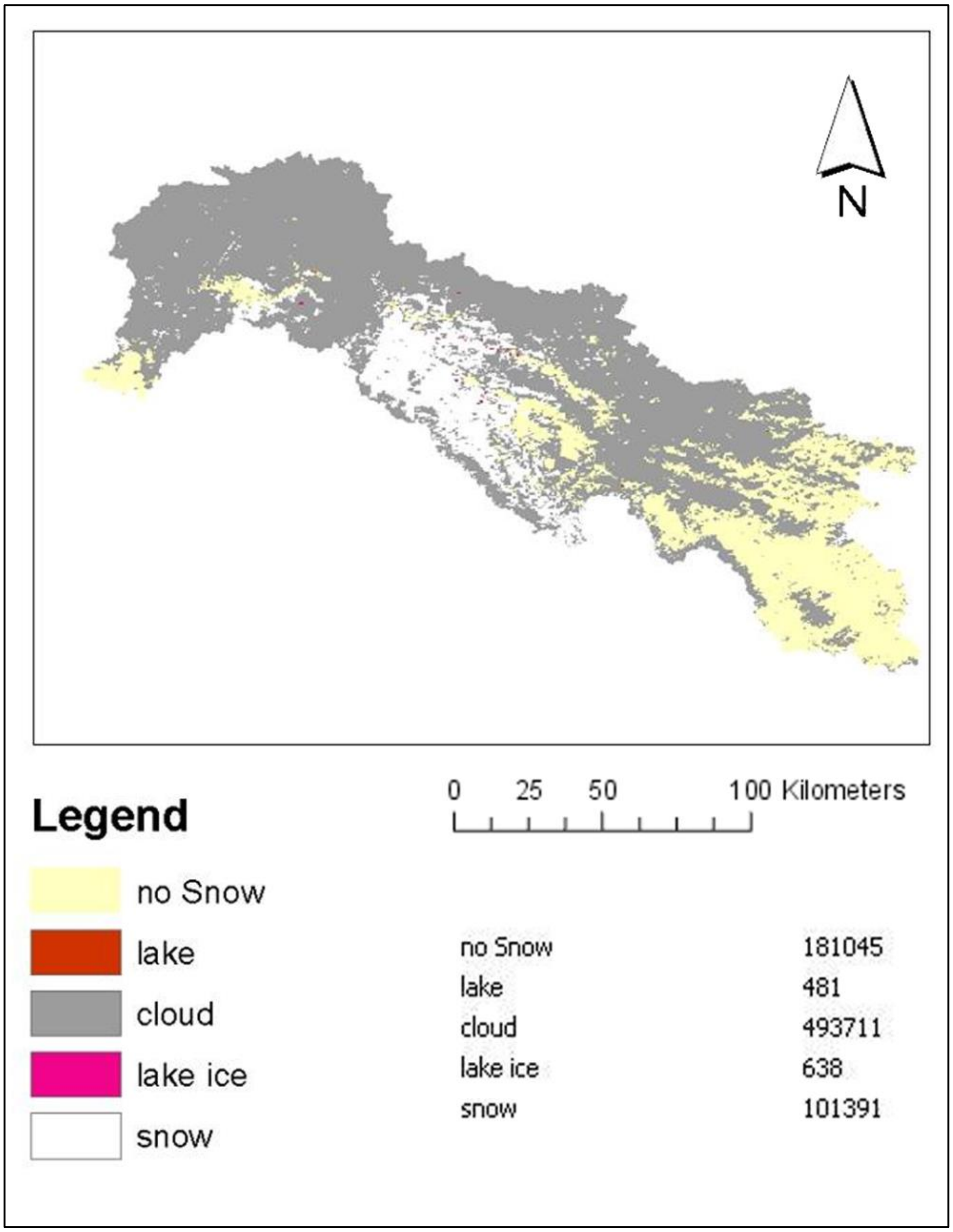


Figure 8: MOD10A1 Imagery after Cloud Removal

3.2.3.7 Snow cover / Snow melt mapping

MODIS snow tools were used to calculate areas of snow cover and cloud cover, along with areas showing pixels of water. Monthly averages were computed from daily statistics and corresponding graphs were generated. Following table shows yearly and monthly sample calculations.

Month	**Snow cover in percentage**
January	7.107159
February	5.193557
March	8.818197
April	7.7138
May	8.063414
June	5.272625
July	2.826599
August	1.662412
September	2.610392
October	6.096994
November	6.778482
December	7.236741

Table 1: Monthly average snow Cover for 2004

3.2.4 Working on Landsat data

The following flow chart shows steps involved in LULC classification using Landsat data.

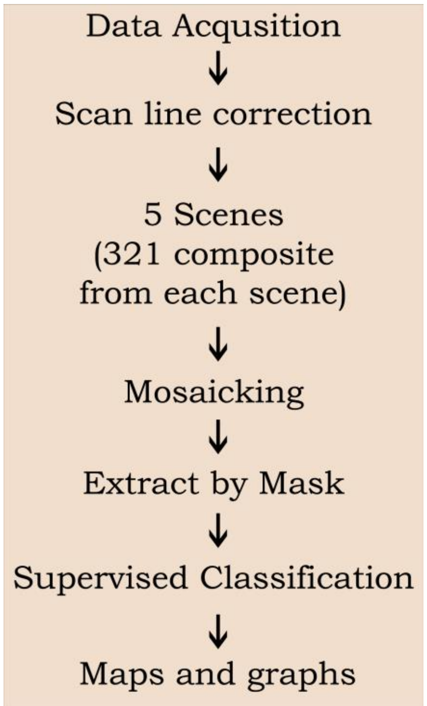


Figure 9: Flowchart showing Landsat processing

3.2.4.1 Data Acquisition

Since the area of interest is a very large, comprising of three mountain ranges, five scenes of Landsat were required to cover the whole area. Data was downloaded from USGS Earth explorer.

Scene	Path	Row
LE71490352005108PFS00	149	035
LE71490362005108PFS00	149	036
LE71500352005179EDC00	150	035
LE71500362005131EDC00	150	036
LE71510362005154EDC00	151	036

Table 2: Scenes of Landsat data used

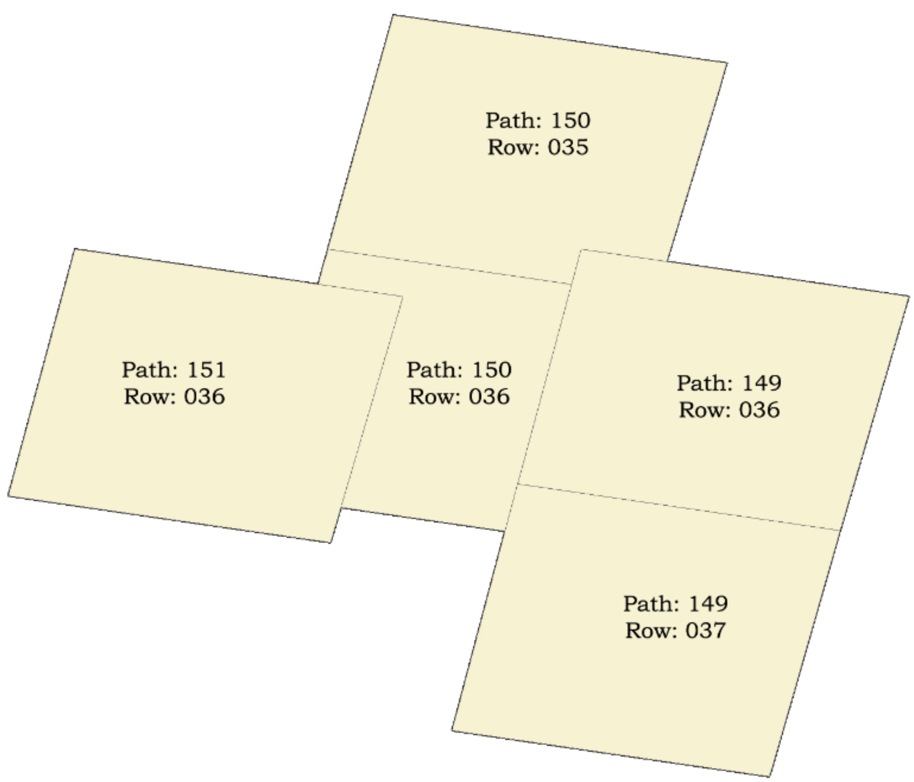


Figure 10: Landsat Path and Rows

3.2.4.2 Scanline Correction, Mosaiking and Extract by Mask

Landsat 7 data tends to be affected by scanline error, so ENVI Gapfill extension was used for filling scan lines using triangulation algorithm in its background.

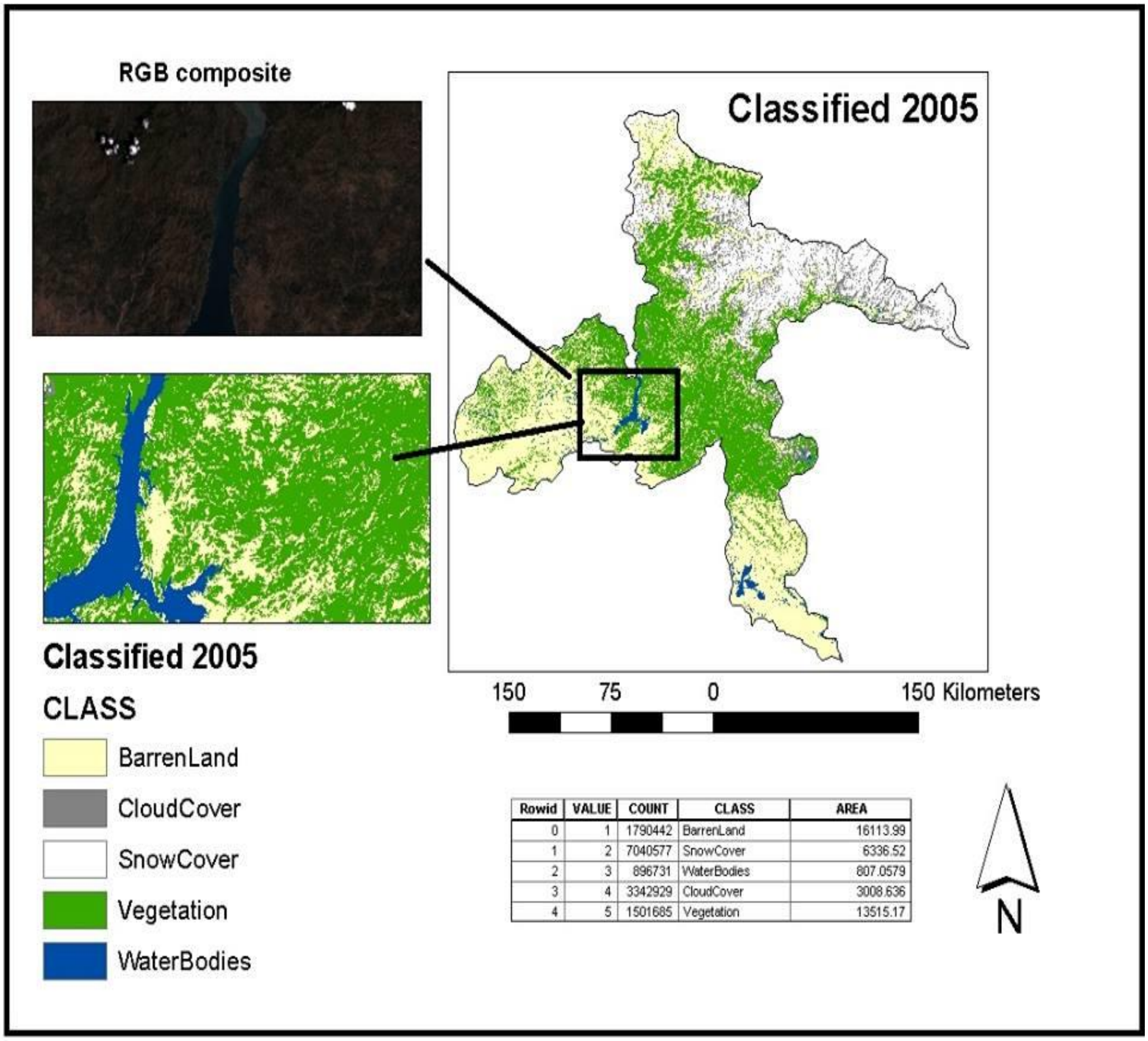
Then mosaicking of data was performed in an ArcGIS environment. Here we adopted two different approaches. Initially, we mosaicked single bands (for example band 1 from each scene) and created a natural color raster. This approach however, caused severe problems of color balancing. Therefore, we shifted instead to making natural color composites from individual scenes and mosaicking composites together. Once this was completed, mask extraction and data classification was performed.

3.2.4.3 Supervised Classification

Supervised classification was done in ENVI by providing training data for five classes. These classes are

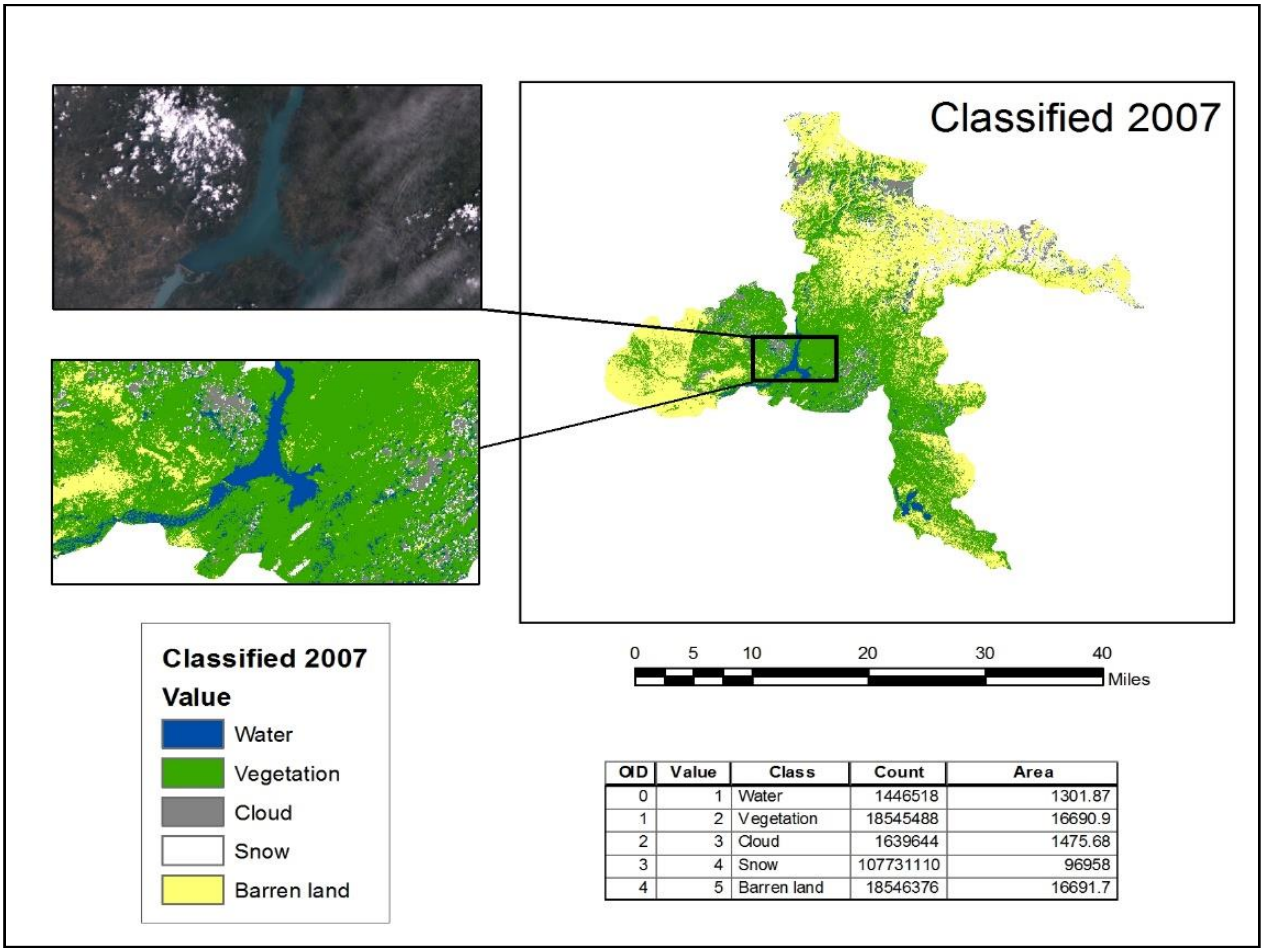
i. Vegetation
ii. Water Bodies
iii. Snow
iv. Cloud
v. Barren Land

Training data was chosen very carefully by using ArcGIS base maps and Google Earth as reference. Special attention was paid to classification of the vegetation class.



Rowid	VALUE	COUNT	CLASS	AREA
0	1	1790442	BarrenLand	16113.99
1	2	7040577	SnowCover	6336.52
2	3	896731	WaterBodies	807.0579
3	4	3342929	CloudCover	3008.636
4	5	1501685	Vegetation	13515.17

Figure 11: Land cover Classification Map of 2005



OID	Value	Class	Count	Area
0	1	Water	1446518	1301.87
1	2	Vegetation	18545488	16690.9
2	3	Cloud	1639644	1475.68
3	4	Snow	107731110	96958
4	5	Barren land	18546376	16691.7

Figure 12: Land cover Classification map of 2007

CHAPTER 4

RESULTS AND DISCUSSION

This section summarizes research aims with analysis and results obtained. Results are then provided in the form of maps, graphs and statistical tables.

4.1 Analysis in GIS Environment

A geographic information system permits handling and manipulation of data. Softwares used for analysis are ArcMap, ENVI 5.0, Erdas Imagine and Grass GIS for environmental correction of landsat imagery. Programming environments, especially python scripts, were used for batch processing.

Following graphs depict snow cover and temperature.

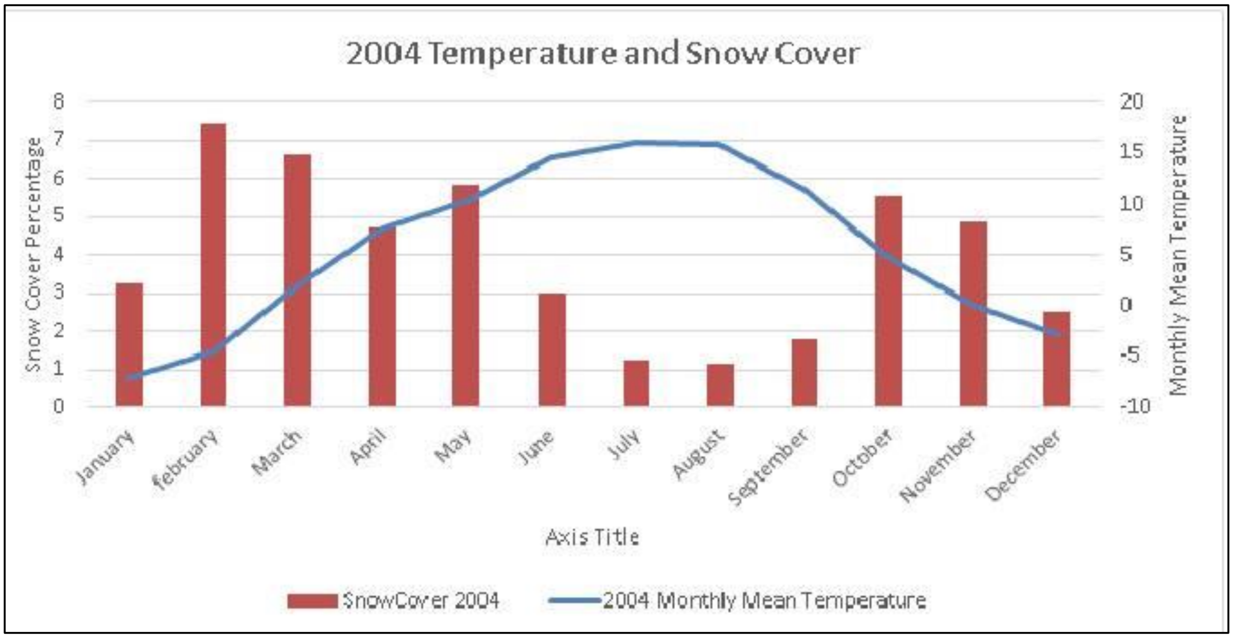


Figure 13: Temperature vs Snow Cover Graph 2004

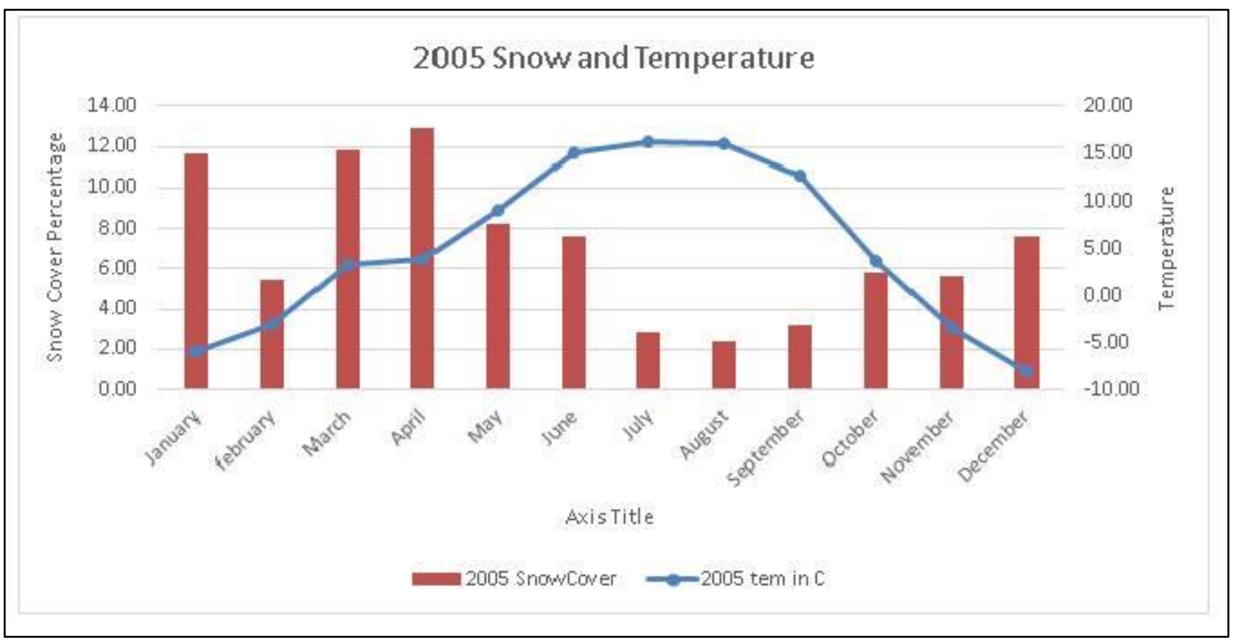


Figure 14: Temperature vs Snow Cover Graph 2005

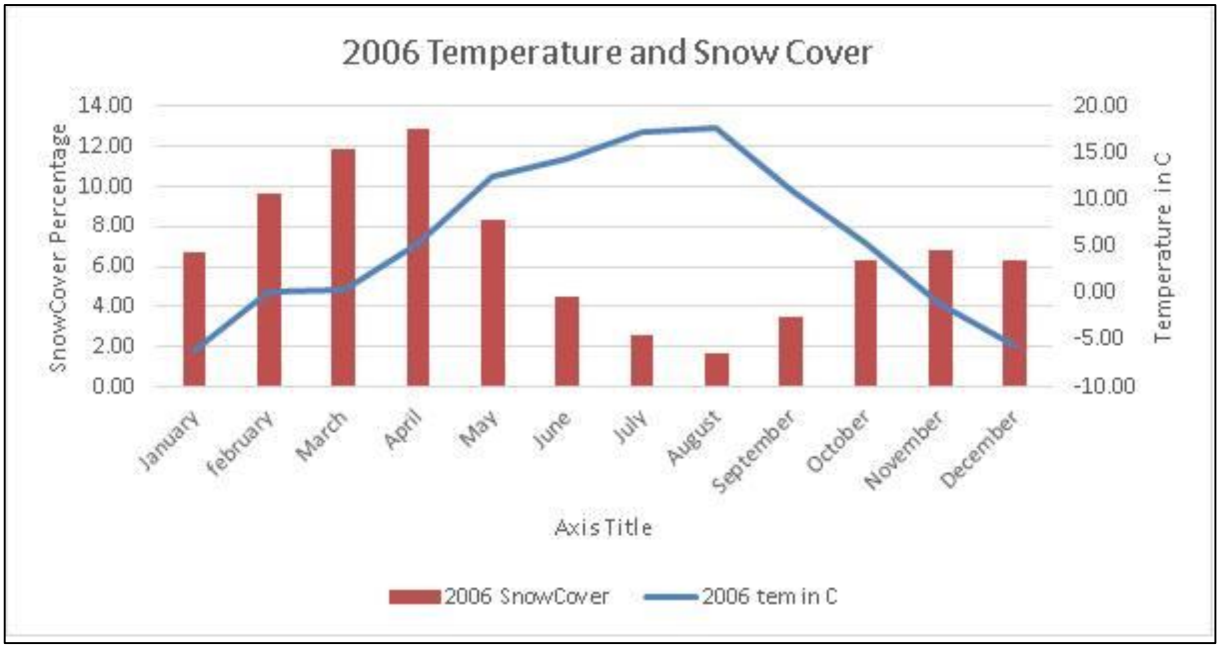


Figure 15: Temperature vs Snow Cover Graph 2006

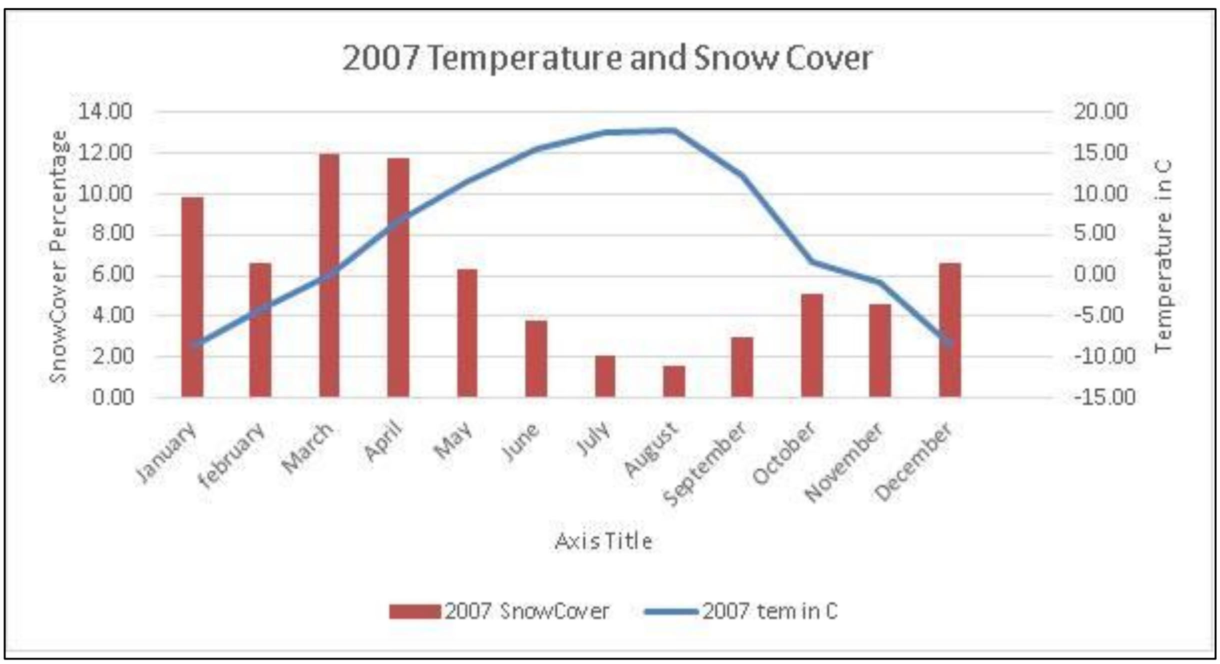


Figure 16: Temperature vs Snow Cover Graph 2007

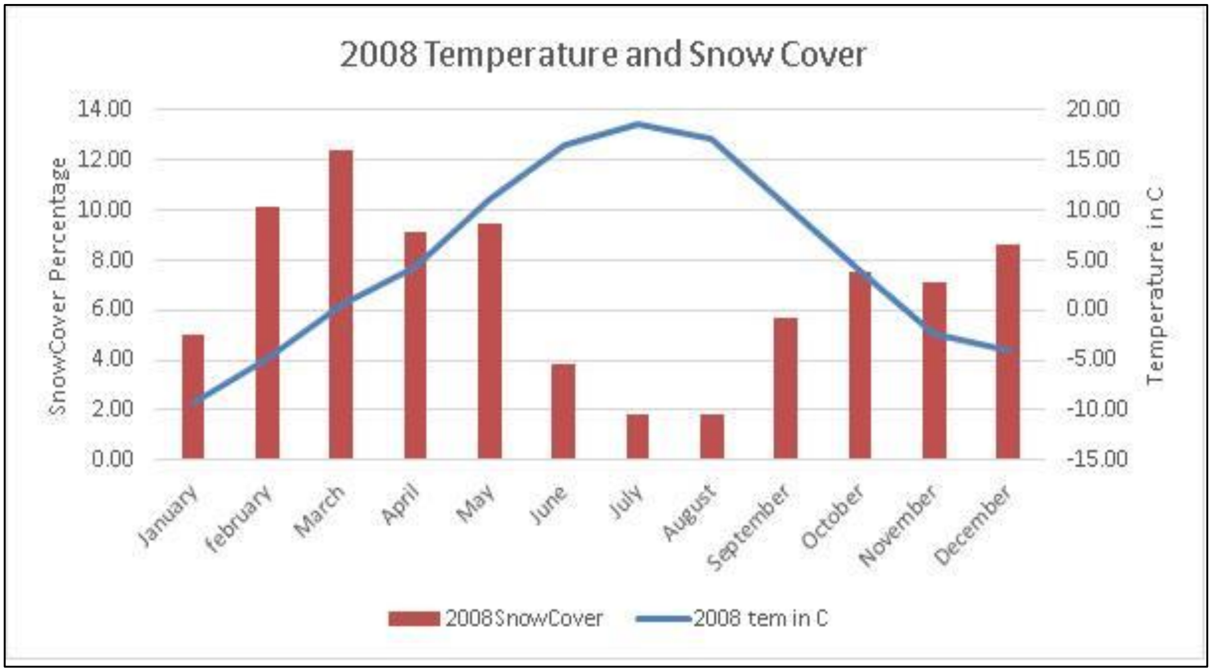


Figure 17: Temperature vs Snow Cover Graph 2008

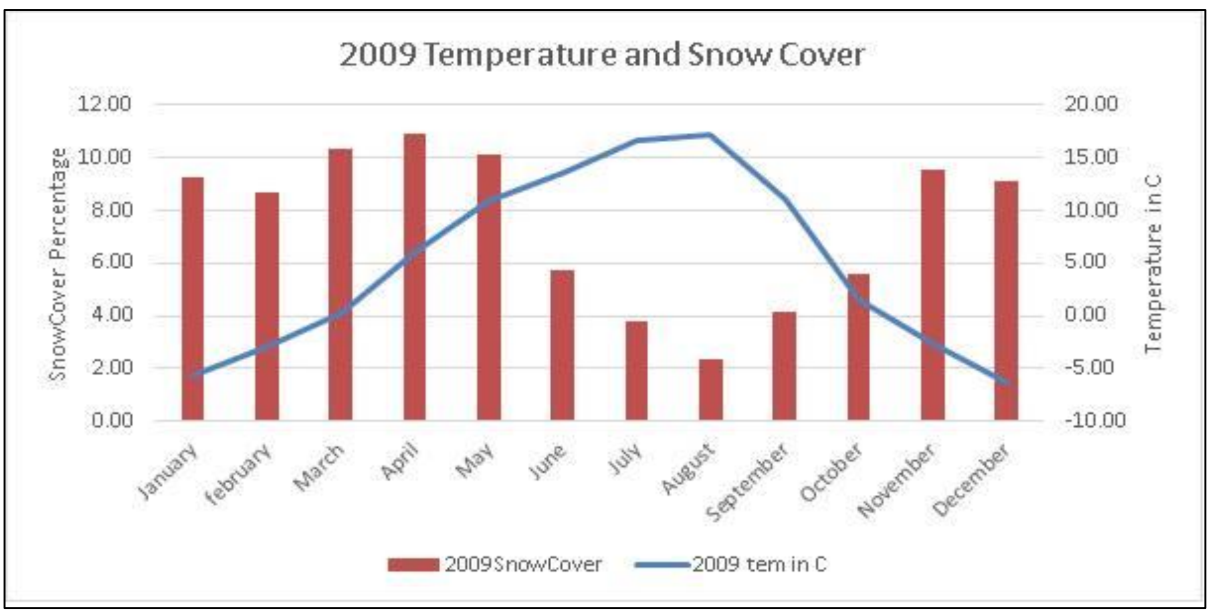


Figure 18: Temperature vs Snow Cover Graph 2009

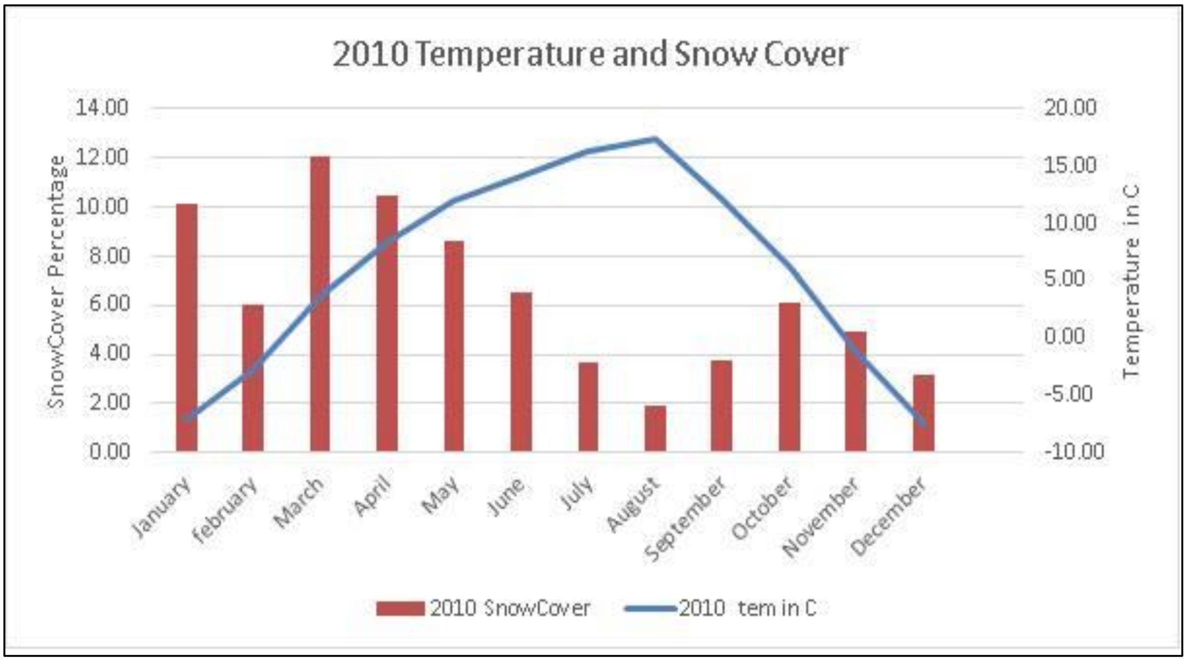


Figure 19: Temperature vs Snow Cover Graph 2010

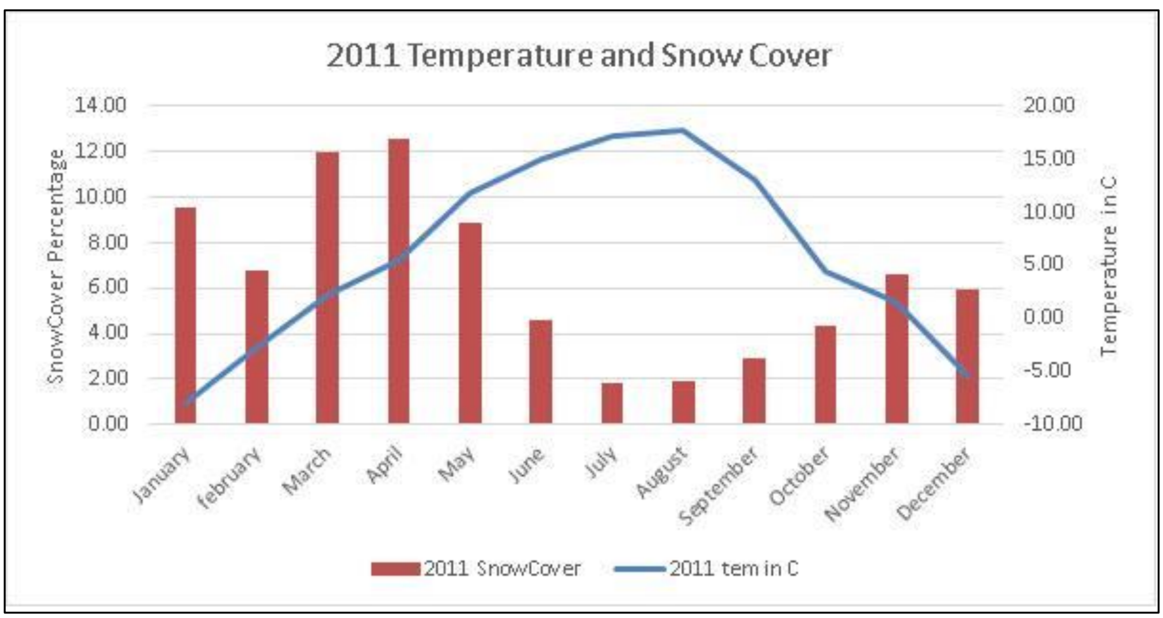


Figure 20: Temperature vs Snow Cover Graph 2011

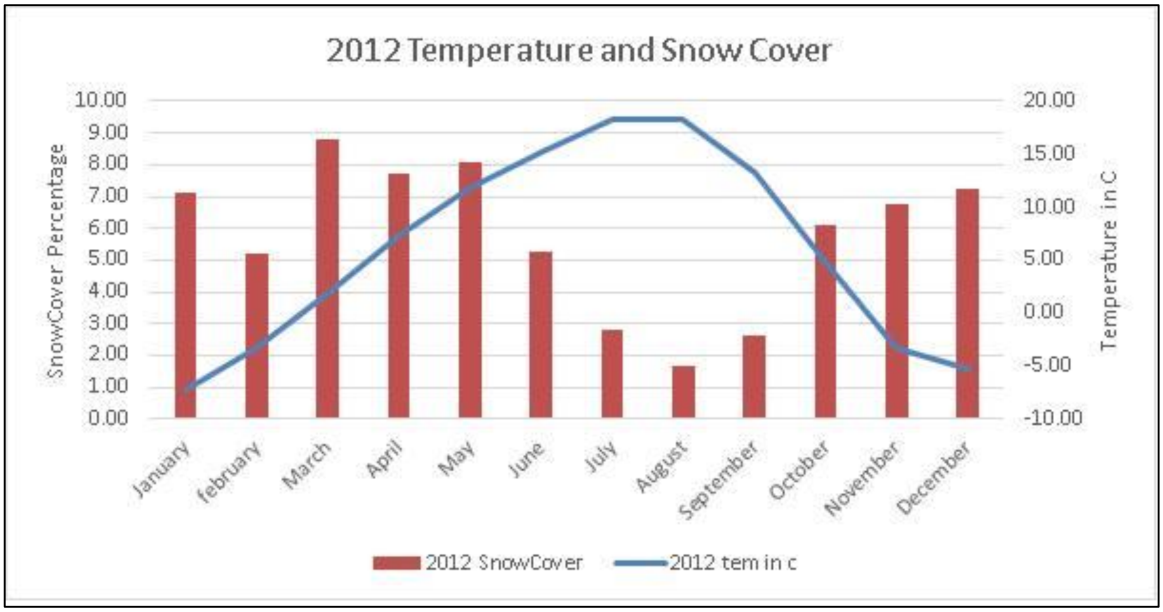


Figure 21: Temperature vs Snow Cover Graph 2012

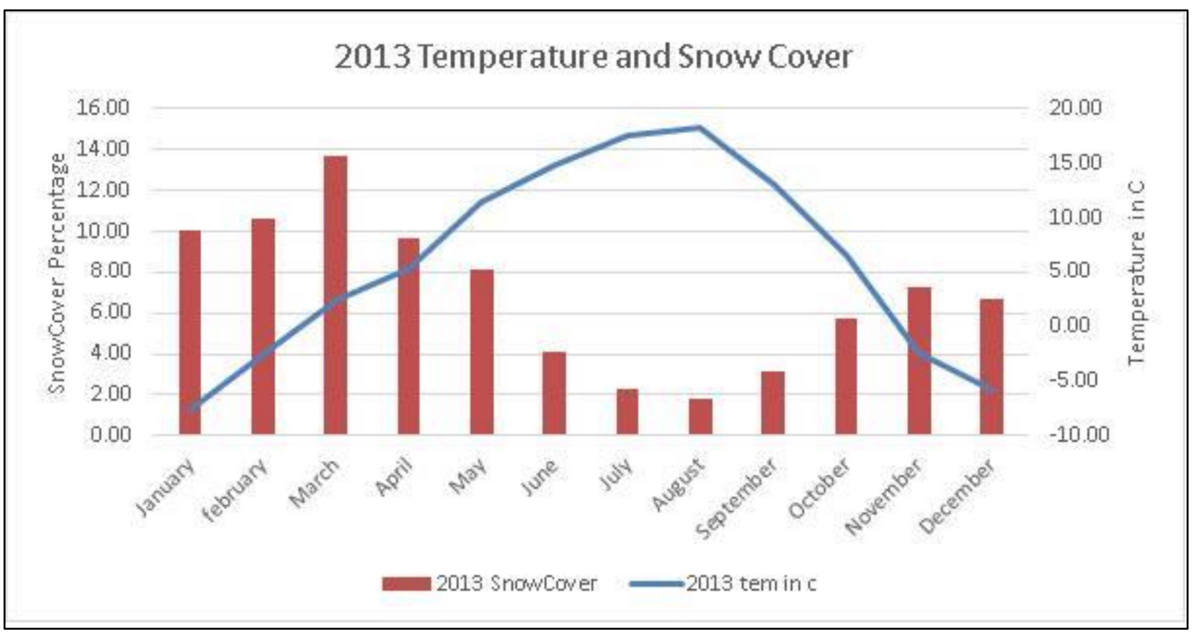


Figure 22: Temperature vs Snow Cover Graph 2013

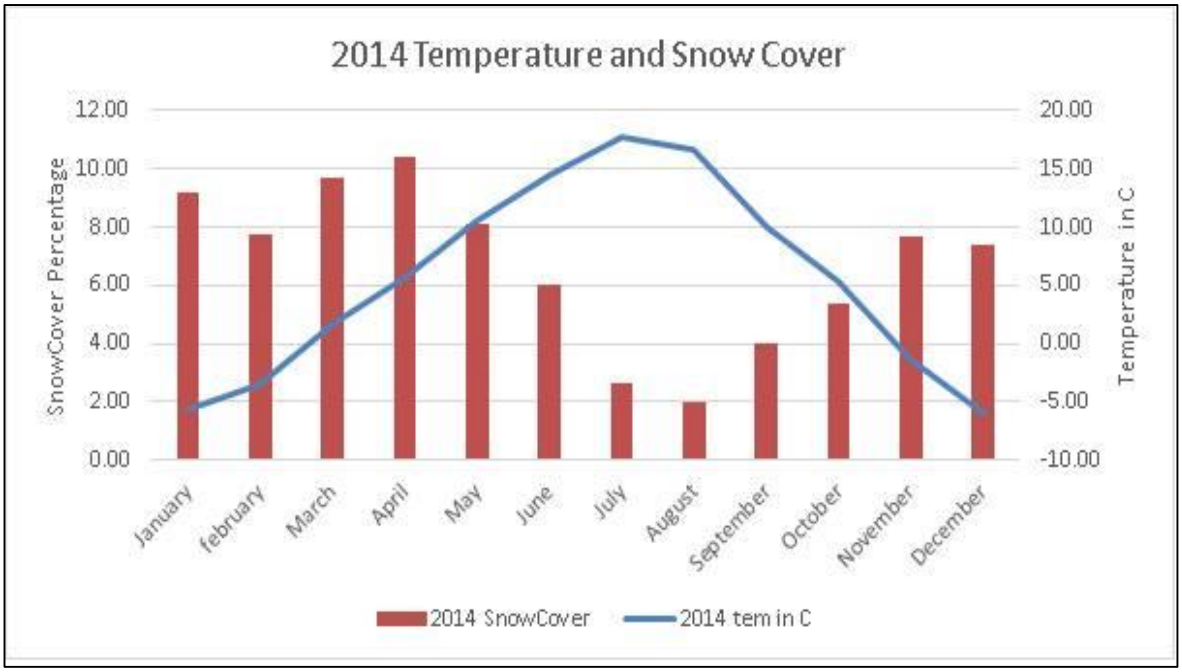


Figure 23: Temperature vs Snow Cover Graph 2014

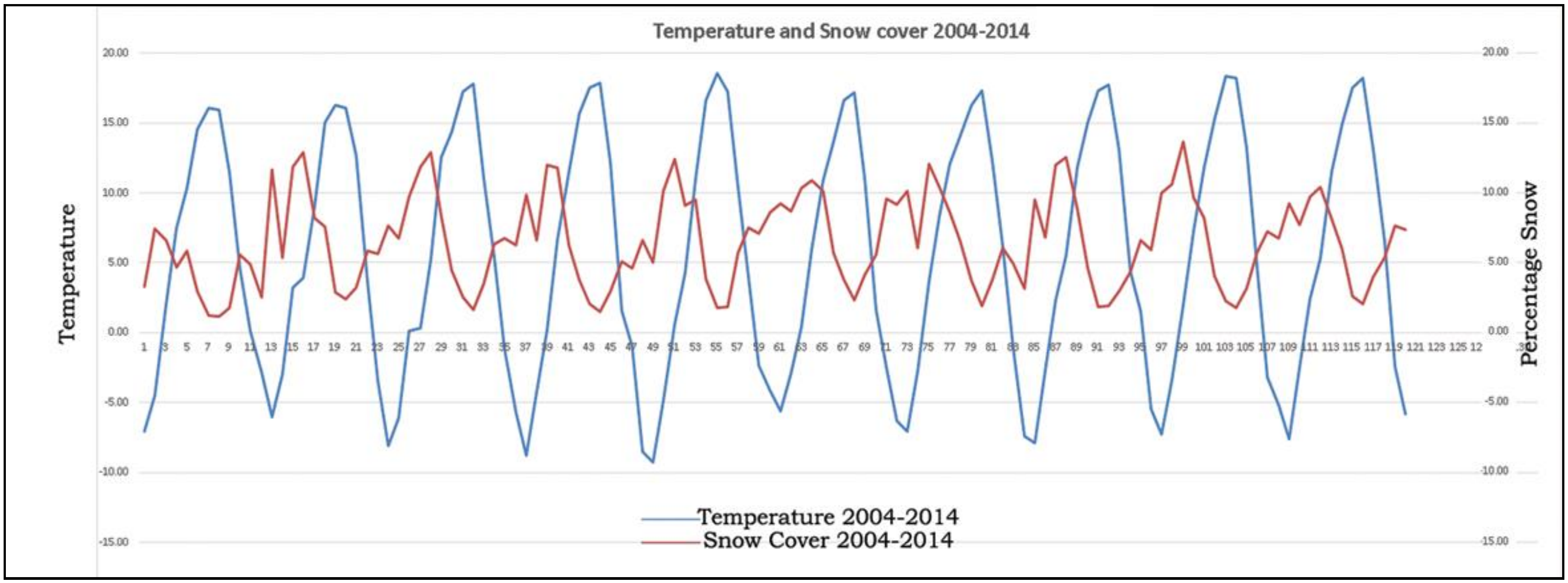


Figure 24: Graph showing Temperature and Snow cover variation trend for 2004-2014

4.2 Analysis of Snow and temperature

Similar trends for all eleven years, 2004-2014, were observed. Snow cover decreases with increase in temperature in the months of June, July and August. Snow cover seems to recover in the winter season with the start of snowfall. Highest temperature peaks occurred in the years 2005 and 2009. In both these years, a large amount of snow cover melt can be observed in the corresponding snow-melt graph. A large percentage of snow cover occurred in 2012-13 during extreme low temperature seasons.

4.3 Land cover classification results

Following table shows area from which snow melted and area of vegetation.

Year	**Vegetation (square km)**	**Snow melted from area**
2005	13515.17	102878.22
2007	6336.52	84134.98
2009	24688.7	50565.15

Table 3: Comparison of Vegetation and Snowmelt

The results shows that in years where there is greater snowmelt, excess water is available for irrigation, hence there is large area under vegetation cover. In contrast, in times with less snowmelt, for example when snow melts only from around 50565.15 km2 area, there is much less vegetation, approximately 24688.7 sq. Km.

4.4 Snow Mass balance

Snow mass balance was calculated using snow depth and snow density recording ERA Interim data. These parameters were multiplied with snow area to find snow mass balance in metric ton units.

A small table showing some of the calculations is given below:

Year	Month	density kg/m3	depth mean monthly meters	snowcover km^2	snowcover m^2	mass in metric ton
2004	January	139.873138	0.235166096	20427.47014	20427470140	671929351.6
2004	February	160.1102951	0.235709086	46417.37388	46417373878	1751766224
2004	March	160.0961355	0.244169083	41380.5744	41380574398	1617588445
2004	April	174.977112	0.232037127	29290.34283	29290342827	1189222665
2004	May	130.8899327	0.237382005	36558.69425	36558694252	1135912070

Table 4: An overview of snow mass balance calculations

4.5 Snow mass balance to water

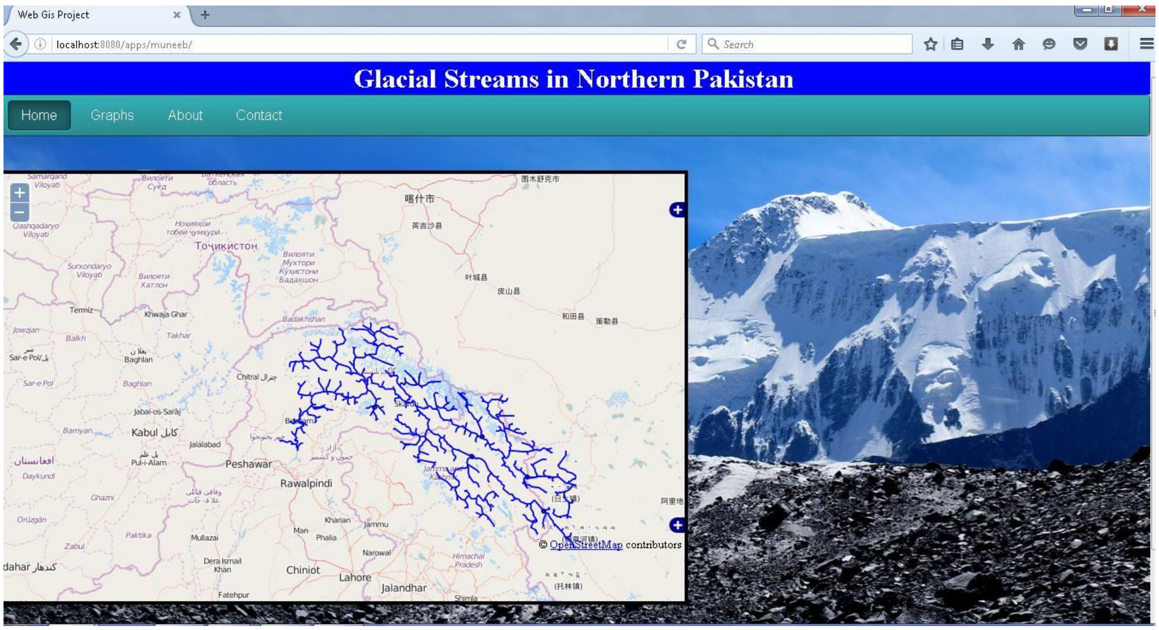
Estimation of fresh water reserves was a very important aspect of this research. This was calculated utilizing prior knowledge of the amount of water produced from the melt down of specific amounts of snow mass. If 10 metric ton of snow is known to produce two metric tons of water, we can reasonably estimate amount of water still stored in the form of snow.

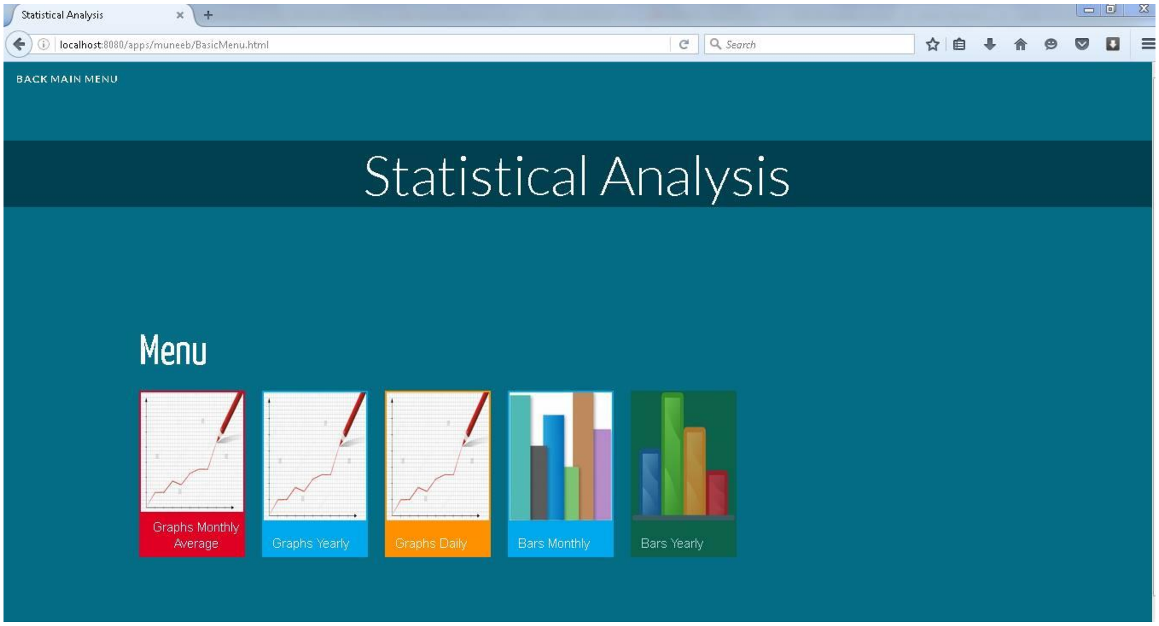
Months	Mass in metric ton	Water (Metric Ton)
January 2004	671929351.6	134385870.3
February 2004	1751766224	350353244.8
March 2004	1617588445	323517688.9
April 2004	1189222665	237844533.1

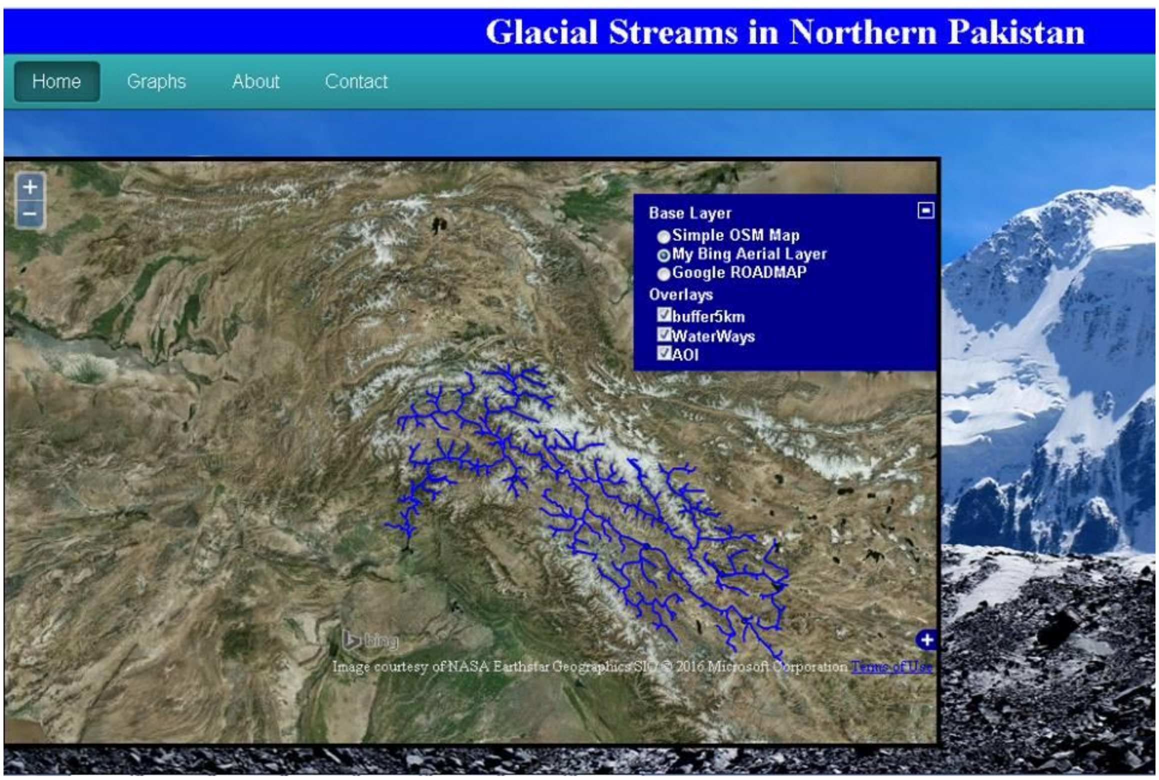
Table 5: Estimate of Water reserve from snow mass balance

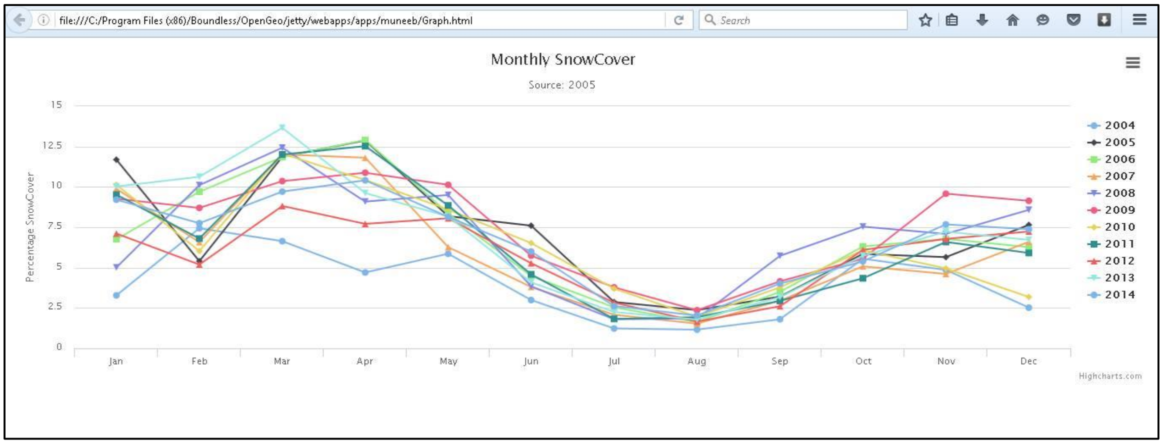
4.6 Web Interface

A static website was built to enable parallel visualization and analysis of graphs and data. The website also allows other researchers working in the field of cryosphere dynamics to view our work, utilize available data and extend research from this point onward.




Statistical Analysis
localhost:8080/apps/muneeb/BasicMenu.html
BACK MAIN MENU
Statistical Analysis
Menu
Graphs Monthly Average
Graphs Yearly
Graphs Daily
Bars Monthly
Bars Yearly


Glacial Streams in Northern Pakistan
Home
Graphs
About
Contact
Base Layer
Simple OSM Map
My Bing Aerial Layer
Google ROADMAP
Overlays
buffer5km
WaterWays
AOI



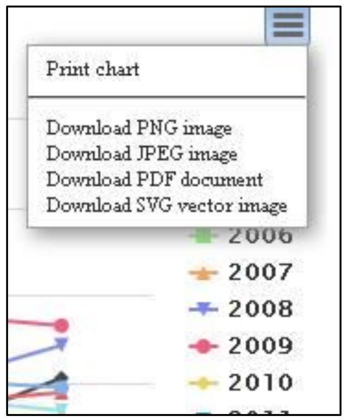


Figure 25: Web Interface – Miscellaneous pages and Download option

4.7 Conclusion

Snow mass balance curves reveal that glaciers are starting to regain their mass balance after having lost mass balance in the middle of the last decade. This research only utilized freely available data. The purpose behind this study was to prove that RS and GIS technology is an effective and low cost tool for snow cover monitoring and mass balance calculations. Continuous monitoring of snow cover dynamics is effective for prediction and mitigation of hazards associated with areas in proximity to glaciated regions. One common hazard is glacial lake outburst phenomenon, which causes severe flash flooding in downstream areas. In particular, snow cover / snowmelt data reveal continuously changing melting patterns, which help concerned authorities to take necessary measures for preserving these storehouses of water and mitigating the effects of global warming.

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