SPATIO TEMPORAL CHANGE OF SELECTED GLACIERS ALONG KARAKORUM HIGHWAY AND PASSU GLACIER LAKE OUTBURST FLOOD MODELING

Yasmeen Anwar

(2015-MS RS & GIS 118191)

A thesis submitted in partial fulfillment of the requirements for the degree of MS Remote Sensing and GIS

INSTITUTE OF GEOGRAPHICAL INFORMATION SYSTEMS

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

ISLAMABAD

AUGUST, 2019

Spatio Temporal Change of Selected Glaciers along Karakorum Highway and Passu Glacier Lake Outburst Flood Modeling

Author
YASMEEN ANWAR
Registration Number
118191

A thesis submitted in partial fulfillment of the requirements for the degree of MS Remote Sensing and GIS

Thesis Supervisor:
Dr. Javed Iqbal

Thesis Supervisor's Signature:

____

INSTITUTE OF GEOGRAPHICAL INFORMATION SYSTEMS
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY,
ISLAMABAD

AUGUST, 2019

Acknowledgements

First and foremost, I'd like to bow my head in gratitude to the Allah Almighty, for enabling me to have completed this research with His blessings.

I'd like to express my deep and sincerest gratitude to my thesis advisor, Dr. Javed Iqbal, Associate Professor and Head of Department, IGIS, NUST, for providing invaluable guidance, advice, creativity, constructive criticism and keen interest in my research work. I'm thankful to him for giving me the opportunity to learn from his experience and having confidence in me. I am indebted to National University of Sciences and Technology (NUST) for providing us a platform to have such an experience.

Besides my supervisor, I would like to thank the rest of my thesis Guidance and Examination Committee: Mr. Junaid Aziz Khan, Dr. Ejaz Hussain and Dr. Abdul Waheed, for their insightful comments, and encouragement regarding the research. I am sincerely grateful to Mr. Junaid Aziz Khan for his timely advice and tireless efforts throughout the research phase.

I am extremely grateful to my parents for their prayers, love and sacrifices for educating me and preparing for my future. Thanks to my siblings and colleagues, for their prayers, support and patience throughout my research period.

The research is a complete mixed package that is directly or indirectly involving the contribution of many personalities. Therefore, I would like to express my gratitude to all the individuals who have rendered valuable assistance to my study.

Dedicated to my exceptional Parents and adored siblings

Table of Contents

List of Figurers

List of Tables

List of Abbreviations

Acronyms	Abbreviations
C.C	Climate Change
GLOF	Glacier Lake Outburst Flood
CPEC	China-Pakistan Economic Corridor
HEC-RAS	Hydrologic Engineering Centers-River Analysis System
GMRC	Glacier Monitoring and Research Center
LULC	Land-Use and Land-Cover
KKH	Karakoram Highway
HKH	Hindukush-Karakoram-Himalayas

Abstract

Glaciers of Hindukush, Karakoram, and Himalaya (HKH), provides the freshwater to Pakistan's river system. The study area includes some part of Karakoram Highway which is part of the China Pakistan Economic Corridor (CPEC). Therefore this area includes the immense importance in economic sector for both countries, i.e. Pakistan and China. The current study provides remote sensing and geographic information system approach for the assessment of glacier cover change along KKH. To assess the temporal change supervised classification was performed in ArcMap. In order to study the GLOF of Passu Lake phenomenon HEC GeoRas and HEC-RAS 5.0.5 model was used. Primary input for HEC-RAS model was DEM. SRTM DEM was used with 30m resolution, and hydrological data of Passu Lake was acquired from Glacier Monitoring and Research Centre (GMRC). HEC-RAS 2D unsteady flow model was used in this study. Results of glacier change maps illustrated notable decrease of almost 3.5 % glacier cover over the period of 23 years. Change detection was also cross-check by GLIMS glacier boundary. Results of this comparison show that Batura, Passu and Gulmit glaciers have been decreased to 0.596, 0.23 and 0.05km respectively from the year of 1999 to 2017. Ghulkin glacier has been increased to 0.157km. HEC-RAS 2D unsteady flow model was run for Passu Lake flood assessment. Comparisons of datasets were done in this study. 2D storage area was used for flood modeling. Results showed that flood area is increased in self-assumed data. Change in flooded area has been observed in each class, in low class area has been decreased to 2.99%, and in medium and high class area has been increased to 1.16% and 1.82% respectively. This study can be helpful for hazard mitigation organizations. This study can be further applied in other study area and datasets.

CHAPTER 1

Introduction

The research project in the current dissertation has been demonstrated in two parts. First, part is associated with the glacier change along the Karakoram Highway. The objective of this part is to highlight the change in glaciers, whether they are increasing or decreasing. The second part includes hydrodynamic modeling of Passu GLOF. The main concern of this part of study was, to examine the extent of flood.

1.1. Background, scope and motivation

Greenhouse gases usage and the increasing temperature is droving researchers to research climate system and related earth systems (Shrouder, 1998). Climate change (CC) is a universal problem, which is triggering the melting of glaciers that leads to shrinking of glaciers mass and causing the floods (Miller, Immerzeel, & Rees, 2012). Climate change and changes on landscapes are relatable because geodynamics controls the mechanisms that join the climatic, tectonics and surface processes. The cryosphere is one of component that couples the earth's system, atmospheric, lithospheric, and hydrologic responses are governed by the glaciers mechanism. Precisely, mass distribution of ice and snow moderately control the atmospheric properties, sea-level changes, erosion, topography evolution, and regional hydrology. Subsequently, scientists have accepted the importance to monitor the fluctuations of glaciers and their latent as direct and indirect symbols of climate change (Shrouder, 1998)

Satellite data from NASA's Earth Observation System (EOS) help in identification for those areas that are changing rapidly and have a substantial impact on sea level, hydrology, economics, and geopolitics. There is number of mountain ranges that have been identified as "critical regions" e.g. Alaska, Himalayas, and Patagonia. In Himalayas, alpine glaciers thought to be very sensitive to climate change because of their array of altitude and inconsistency in debris covers. To study the relationship between climate and glaciers western Himalayas is best place because it already experienced the intense climate change effects and has substantial ice volume.

Glaciers of Pakistan are a bit difficult to understand because of their composite topography, the rareness of field measurements and limitations related to extracted information from satellite imagery. Information is limited about; 1) numerous glaciers and scattering; 2) Regional trends; 3) melted water from glacier and its effect on sea-level rise; and 4) natural hazards e.g. landslides, outburst flooding etc. (Shrouder, 1998)

Pakistan has the connection point of the world's biggest mountain ranges, i.e. Himalaya, Karakoram and Hindukush (HKH) having biggest glaciers besides the poles (Anwar & Iqbal, 2018). Global climate change has affected the snow and glaciated surroundings of Hindukush-Karakoram-Himalaya (HKH) region of Pakistan (Ashraf, Naz, & Roohi, 2012). Glaciers of HKH region are providing water to Pakistan's water system (Rasul, Chaudhry, Mahmood, Hyder, & Dahe, 2011). Pakistan water resources mainly depend on melted water of glaciers that are situated in HKH ranges. Melted water is used for multiple purposes, e.g. domestic, agriculture, generating the electricity, etc. (Anwar & Iqbal, 2018). The snow cover area of trans-Himalayan upper Indus basin is almost 20,000 km^2. Most massive glaciers are found in the Himalaya Karakoram region. There are almost 7000 glaciers in Karakoram Range in which 15 are the largest which cover almost half of glaciered area (Yao, 2008).

Glaciers of Karakoram have declined by 5% since the early 20th century, but declination slowed down in the 1970s and some of the glaciers experienced the advancement (geografii & Kotliakov, 1997; Mayewski & Jeschke, 1979). Retreating was again seen in 1980s but not with intense loss but in 1990s it was reported that glaciers are stabilizing and in some high altitude increasing (Hewitt, 2005; Immerzeel, Droogers, De Jong, & Bierkens, 2009). From 1930s to 1990s glaciers were retreating, but some minor revert in 1970s, consequently by 2010 none of them were even close to their original or maximum extent of last 130-150 years, with exceptional case of Ghulkin. Ghulkin is one of the other glaciers that have advanced in recent years (Scherler, Bookhagen, & Strecker, 2011). Numerous studies conclude that Karakoram glaciers act differently than Himalayas and more studied glaciers of Europe and North America. High altitudinal snowfall, glacier topology, and the verticality (rock walls) and other conditions prevail above 4000 m elevation, which was previously neglected (Hewitt, 2011).

As the climate is changing glaciers are melting rapidly. Therefore this HKH region faces hazards, e.g. floods, avalanches, land sliding, etc. In Pakistan, glaciers are melting with the rate of 40-60m per decade and causing an increase in glacier lakes, that is why Glacier Lake Outburst Flood (GLOF) is major threat to this region. In the process of GLOF formation v-shaped valleys can transform into immense devastation. In Pakistan, the total 5218 glaciers are present, and 2420 glacier lakes are present in them. Out of 2420 glacier lakes, 52 lakes are categorized as hazardous (Rasul et al., 2011). Himalayan's glaciers are decreasing like all over the world's glaciers, but glaciers of Karakoram are behaving differently, they decreased in past but after 1990's they began to increase. In 13, glaciers expansion has been seen between 1997- 2002 (Hewitt, 2005). Karakoram glaciers are acting differently, it is observed that glaciers of this region are surging from 1860s and in recent years, rapid increase in glacier tongue triggered by heave raises the threat of GLOF. In Karakoram region 35 GLOFs are stated since 1826 (Rankl, Vijay, Kienholz, & Braun, 2013).

The lakes situated at bottom of glaciers are mainly dammed by lateral or end moraine where the tendency for breaching is high. These lakes may be hazardous because it holds a huge amount of water. Rupturing or a sudden release of water from these lakes may cause the flash flood and affect the downstream areas by the flood. In order to assess the flood hazard from these lakes it is important to observe these lakes via remote sensing (satellite imagery) and monitor their extent and other change (Jain, 2012).

Passu lakes have reported the two outburst floods in the last forty years. This caused disastrous damage to houses and downstream infrastructures of Passu village. These events were concomitant with incidence of heavy rainfall in just two hours and speed up the melt rates due to 14 days extended heatwave. (Rasul et al., 2011)

GLOF hits in 6th January 2008, at Passu glacier. The major cause for this event was the high liquid precipitation, which was down poured on the event day and the next day of the event. This rain may cause the melting of snow because of its latent heat, and triggered to detach the ice from glacier, and fall into the lake and produced the outbursting of flood (Din, 2014).

Understanding of glaciers and glacier lakes is essential not only for water management but also for hazards management lie, GLOFs downstream. Unluckily understanding of mountainous headwater of Indus River and particularly of snow and ice situation is very poor. The geomorphologists of International Karakoram Project (IKP) have surveyed in 1980, the Hunza valley between Gilgit to Gulmit besides the Karakoram Highway. They identified the traces of 339 catastrophic events containing a varied range of short-term mass movements (Goudie, 1981; Miller, 1984). Among these hazards, damaging ones are directly related to movement of glaciers, when glaciers retreat or spread headed to outburst floods of ice-dammed lakes which cause the damaging of cultivated lands, downstream infrastructure, and irrigation system. The importance of this situation has exaggerated over past century because of increased glacial lakes. Lakes those are formed on glacial terminuses, formed by current receding processes of glaciers (Ashraf et al., 2012).

The key application of optical satellite, is glacier mapping that has been used widely, especially after the free availability of Landsat Imagery. Outline of glaciers is very important to monitor for any calculations and demonstrating concerning to glaciers. Glaciers classification is based on substantial difference between glacier and snow spectral reflectance (Paul, Winsvold, Kääb, Nagler, & Schwaizer, 2016).

To monitor the glaciers, GIS and RS methods are way too easy as compare to the old methods. Classification of glaciers and related GIS methods to the extraction of glaciers from Landsat imagery are very useful and easy for glaciers mapping. There are number of methods to monitor the glaciers i.e. Normalized Difference Snow Index (NDSI), image classification, visual interpretation, etc. (Anwar & Iqbal, 2018; Shukla, Gupta, & Arora, 2009).

There are many problems e.g. geopolitical restrictions, remote areas, etc. therefor glaciers of Pakistan must be assessed through RS. The new advent of sensors and geographic information technologies (GPS, GIS), scientists can monitor the glaciers and related other parameters e.g. equilibrium line altitudes, ice velocity fields and other things those have scientific importance (Bishop & Shroder, 2004;Bishop et al., 2004). RS analysis of glaciers is usually focused on image interpretation, identification, mapping and characterization of glaciers, through quantitative approaches such as pattern recognition and image transformation were used in trying to distinguish snow and glacier. These were the characteristics of glacier studies in 1970s (Shroder, Dimarzio, Bussom, & Braslau, 1978; Williams & Ferrigno, 1998).

There is number of techniques that are used for mapping the GLOF hazard, CORONA, Resourcesat-1 (IRS P6) LISS III and Landsat satellite data beside empirical and probability model can be used for temporal analysis and estimation of potential of GLOF hazard (Raj, Remya, & Kumar, 2013). Hydrodynamic modeling can be used for mitigation of GLOF events. There are number of software that can be used to estimate the discharge flow of GLOF e.g. NWS, HEC-RAS, FLDWAV, MIKE 11, etc. Results can be in form of graphs, flood maps and GLOF vulnerability maps, which can be useful in GLOF mitigation (Bajracharya, Shrestha, & Rajbhandari, 2007)

Karakoram highway plays an important role in China Pakistan Economic Corridor (CPEC), which starts in Hassanabdal city of Pakistan and ends in Kashgar, China. Therefore the glaciers and Passu

GLOF alongside the KKH were chosen, because if any change happens in these glaciers or GLOF happened than KKH will directly affect.

1.2. Research hypothesis and research questions

The research hypothesized that glacier change is one of the major contributing factors of floods and GLOF. The research questions that are expected to be explored in this study include whether the glaciers are changing in the study area? To what extent did the glaciers have been changed? Are the glaciers declining or spreading? What are the causes behind the glacier declination and advancement? To what extent GLOF can damage the study area?

1.3. Objectives

The objectives of the current study were:

1. Mapping the temporal change of glaciers from 1994-2017 and its correlation with weatherdata.
2. Hydrodynamic modeling of Passu GLOF using 2D unsteady flow of HEC-RAS.

Chapter 2

Materials and Methods

Particulars of the research's study area and materials and methodology used are enlightened in this chapter. The comprehensive account of research and techniques implemented for each objective has been described in the subsequent section.

2.1. Study area

The study area is includes some part of Upper Gojal-Hunza valley of Pakistan. It almost started from Gulmit and ends into Sost village. It covers almost 70.7km distance in Karakoram Highway Figure. 1. The study area includes major 4 glaciers alongside the KKH i.e. Gulmit, Ghulkin, Passu, and Batura. Coordinates of Batura glacier is 36◦32'N 74◦30'E. Passu glacier lies in south of Batura Glacier. Location of Passu glacier is 36.4667◦N 74.7667◦E. Main areas of study area are Passu village, Gulmit Village and Hussaini village, Ghulkin, Gojal Valley etc. (Musofer, 2010).

2.1.1 Physiography

Hunza valley is situated between the 36.316942°N 74.649900°E coordinates. Hunza valley has the highest mountains like Rakaposhi, Hunza peak, Ultar Peak, Ladyfinger peak, etc. Hunza valley is divided into three subdivision; 1.Gojal Valley/Upper Hunza 2.Lower Hunza and 3.Central Hunza. The study area of this study is situated in Gojal Valley/Upper Hunza. It is the most upper part of Hunza valley which bordered with China through Khunjerab Pass. KKH passes through this area and meets its endpoint in Kashgar in China. The study area is full of glaciers, mountains, rivers, and lakes. The major river of study area is Hunza river which is a tributary of Indus river.

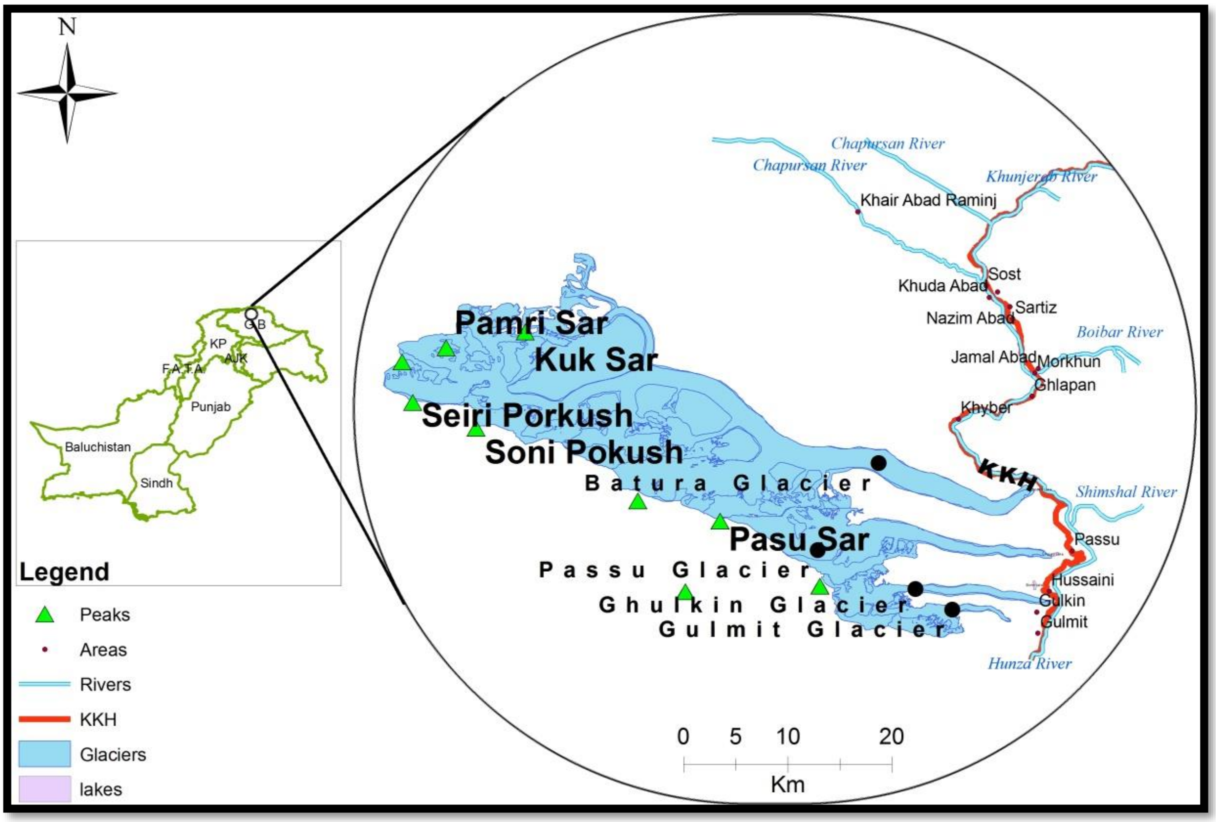

Figure 1. Study area showing glaciers(Batura,Passu, Gulmit and Ghulkin), major towns and Passu lake along Karakoram Highway.

2.1.2 Climate

The climate of Karakorum Range is subjected to Asian Monsoon, which produced 80% of precipitation of southeastern part of Karakorum region. Precipitation gauging are not available in high altitude if they are present, they are mostly in the bottom of the valley, which does not depict the true precipitation values of high altitude area. And for snow measurement, there are scarce of equipment e.g. snow courses, snow pillows, etc. (Immerzeel, 2012).

It has been recorded that precipitation in Karakorum Range is 1600-1800 mm yr^{-1}. High amount of precipitation has been observed in Karakorum Range since early 1960s. The Hunza valley has a tourist attraction because of its scenic beauty. Summers are much cooler and winters are severe cold.

2.2. Dataset used

To identify the temporal change of glaciers satellite imagery is the foremost step. To correlate the change in glaciers with climatic components, precipitation and temperature data was also used. Precipitation and temperature are the main components of climate.

DEM was used for hydrodynamic modeling of GLOF, to collect the information regarding to lake and surroundings. Passu lake hydrology data which includes the discharge flow was also used to run the model. The major cause of GLOFs are the global climate change, which affects the glaciers to increase/decrease. Datasets used in this study is described in Table 1.

2.2.1 Satellite images

For this study, Landsat 5,7and 8imagery has been used. Landsat is a joint program by USGS and NASA which is providing longest continuous space-based earth's data. It is started in 1972 to till present. It has 8 level satellites according to their newness and advancements. We have used Landsat 5,7and 8 because of its free availability. Images of Landsat5 for 1994 and 2002, Landsat7 for 2009 and Landsat8 for 2013 and 2017 were used. Landsat imagery has the 30 meters spectral resolution. Images were downloaded with less than 10% cloud cover and for summer months (September and august).

2.2.2 Hydrological data

Hydrometeorological monitoring station is operational since 2010 at the Passu Lake. This equipment was installed by GMRC department of WAPDA in October 2010, at the altitudes of 36°27′28″N and longitude 74°52′57″E. This equipment includes data logger and pressure transducers. Gauge is located about 1km from the KKH Bridge just downstream of the channel issuing from the lake (Shakoor, 2019).

Data is acquired from 10th June 2011 to 14th August 2011. This data consist on discharge values of Passu lake at the hourly basis of daily.

2.2.3 Climatic data

To correlate the glacier change with climatic data precipitation and temperature data was acquired from Pakistan Meteorological Department (PMD), Islamabad. Climatic data were collected for two stations i.e. Khunjerab and Hunza for the years of 1995-2013 and 2007-2017 respectively.

2.2.4 Digital Elevation Model (DEM)

DEM of 30m resolution was used for this study. SRTM DEM was downloaded from the USGS website with the help of shapefile of study area. Dem was used in ArcMap to make a Triangular Irregular Network (TIN) file which was further used in HEC-RAS 2D modeling.

Table 1. Data sets and its description.

	Features	Specification	Sources
Datasets used	Remote sensing data	Landsat images Digital Elevation Model (DEM)	Earth-Explorer https://earthexplorer.usgs.gov/
	Climatic data	Precipitation data (mm) Temperature (min-max)	Pakistan Meteorological Department (PMD)
	Shapefile	Rivers Roads	Diva-GIS https://www.diva-gis.org/
	Hydrologic data	Discharge flow of Passu Lake	Glacier Monitoring and Research Centre (GMRC)

2.2.5 Hydrologic Data

Hydrologic data were acquired from Glacier Monitoring and Research Centre (GMRC). GMRC is a department of Water and Power Development Authority (WAPDA). Hydrologic data were consisting of discharge flow of Passu Lake. The data was available only for some months that is why we have used discharge flow values of summer months i.e. 10th June 2011 to 14th August 2011, because summer values were high as compare to winter because in winter lake remain frozen, and there is very low discharge flow.

2.3. Software used

Software used in this study are; ArcMap 10.5 which is a software of Environmental System Research Institute (ESRI), ERDAS Imagine 14 from HEXAGON Geospatial, HEC-Geo RAS which is an extension of ArcMap and HEC-RAS 5.0.5 version, which is a software of US Army Corps of Engineers.

2.4. Methodology

Graphical representation of complete methodology for first and second objective is described in Fig 2 and 3, respectively.

2.4.1 Glacier change mapping

To monitor the change in glaciers, supervised, maximum likelihood classification method was used in this study. Classification of land cover comprises assigning pixels to the class which gives information about land cover. Land use and land cover is an essential part of remote sensing that has been used in many analysis for example change detection, urban detection, etc. Classification can be done with two methods; 1.per pixel-based and 2.object based methods. Object-based method can be used in high-resolution imagery, whereas pixel-based classification can be used in low-resolution imagery. Pixel-based classification on 30m resolution imagery of Landsat satellite was done in this study. As our imagery has low resolution, Google Earth imagery was used to see the clear picture of our study area. The classification is accomplished using the following 3 steps i.e., Collection of training sites, Assessment of training samples by their signatures and spectral patterns and Classification ofthe images.

Almost 40 to 50 training sample were selected for each class, they were then matched with Google earth imagery. Supervised classification was done in ArcMap software. The main emphasis of our study is to monitor the change in glaciers, therefore, study area was subdivided into 5 major or general classes. Glaciers, water, vegetation, open land and Debris

2.4.1.1 Accuracy assessment

Image classification was done by visual interpretation; therefore to rectify our results whether the results are correct or not, accuracy assessment method was performed. Accuracy assessment in actual is a method to rectify the classified results with more authentic data source or ground truth data. In this study Google earth imagery was used, as authentic data sets because ground truth data was not available nor done any survey of study area. Accuracy assessment for the classified images is performed in ArcGIS using 3 Geoprocessing toolsi.e., Create accuracy assessment point, update accuracy assessment points and compute the confusion matrix.

For accuracy assessment firstly, we have generated the random points from ground truth (Google earth imagery) and secondly compared these points with detailed result in confusion matrix.

2.4.2 Glacier lake outburst flood modeling methodology

For GLOF modeling, there is number of software that can be used, but in this study HEC-RAS 5.0.5 was used because it is free availability. For Passu Lake Flood HEC-RAS and HEC-GeoRas was used in this study.

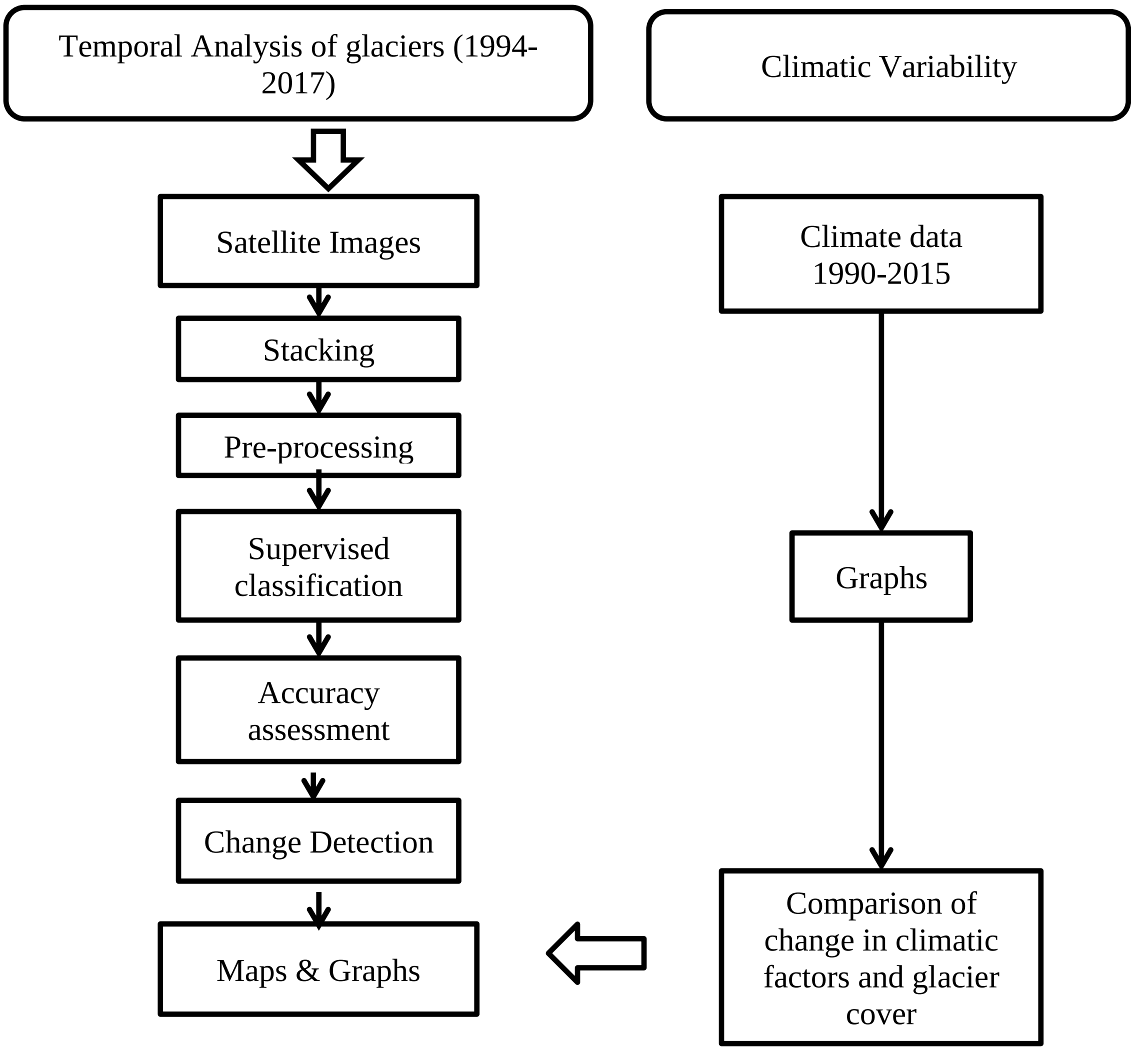

Figure 2. Methodology of glacier change detection (1st objective).

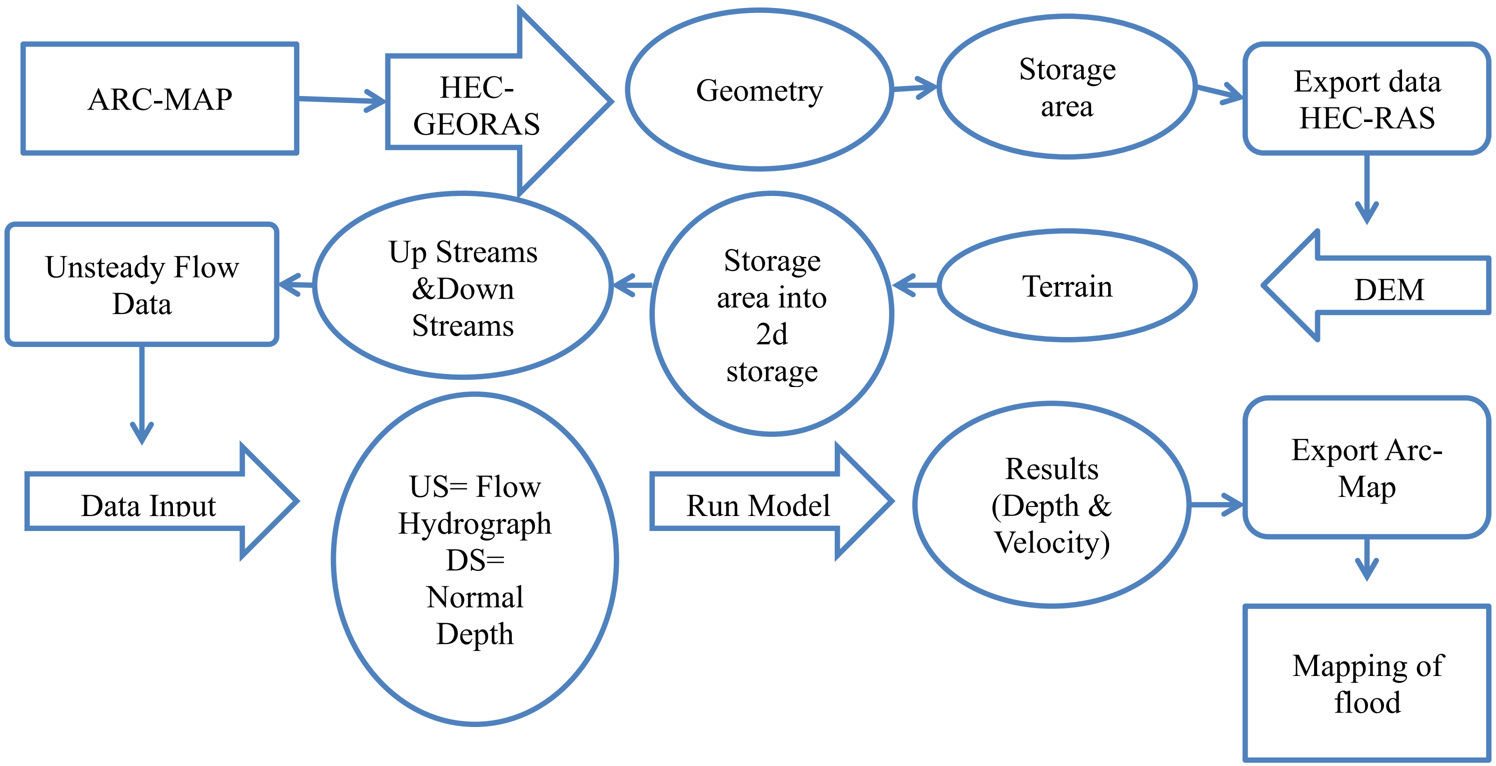

Figure 3. Methodology of HEC-RAS 2D modeling (2nd objective).

Table 2. Description of the Land-use and Land-cover classes.

Classes	**Description**
Glaciers	It includes all the glacial area and snow.
Water	It included all water bodies present in study area i.e. Hunza river, lakes, tributaries etc.
Debris	It includes the debris of glacier which is mostly present in the tongue of glaciers.
Open-land	All the barren/open mountains and land.
Vegetation	It consist of all type of vegetation i.e. trees, shrubs, grass and cropland etc.

Data is gathered from 2 major sources; 1. Hydrologic data of Passu Lake from GMRC and 2.DEM downloaded from earth-explorer website. Landsat imagery was also used in data preparation for flood modeling. Geometry for flood modeling was prepared in ArcMap using the HEC-GeoRas extension. Geometry then exports into the HEC-RAS software where the flood modeling was done and then the results of flood modeling again exported into ArcMap to prepare the flood categorized maps. The flood was classified into three major classes depended on water depth and velocity i.e. Low, Medium and High depth and velocity.

2.4.2.1 Data preparation for hydrodynamic modeling

2.4.2.1.1 DEM

DEM was used in the preparation of geometry for HEC-RAS modeling. SRTM DEM with resolution 30m was used because it is freely available on USGS website. Both SRTM and ASTER DEM were used for this study but the results are clearer and correct in SRTM DEM. DEM was used with fill process.

2.4.2.1.2 Triangular Angular Network (TIN)

With the input of DEM, TIN file was genersated, which gives us elevation, streams, and other information. TIN was then exported into the HEC-RAS, in RAS-Mapper window. In HEC-RAS it is known as terrain of our study area. Terrain represents all the depression, slopes, and elevation of study area. With high-resolution DEM, TIN will give more and clearer terrain information.

2.4.2.1.3 Geometry

For flood modeling, geometry was made in ArcMap on TIN layer. In geometry cross-sections, river, riverbanks, levees, bridges, streams, stream center, storage area, etc. can be made by using the digitization tool. Data for cross-section should be very clear. These all geometry requires bathymetric information of lake, which is absent in our study. This information can be collected by going on survey or by some agencies which collect this data. In this study 2D unsteady flow model was used, which can be only run on storage area (USACE, 2016). Digitization of the storage area from the study area was done using the Landsat and Google Earth image. After that it was exported into HEC-RAS model where it was converted into 2D storage area. 2D computational mesh was done in it with the cell size of 10*10. Mesh process is a hit and trial method, study area of this study is very small therefore small cell size mesh have been used. Mesh process is very important because each and every cell gives you elevation information. Manning's value was also added in this section which was 0.06. Mesh is representing in Fig

2.4.2.1.4 LULC maps

Land use land cover map was generated by supervised classification. LULC maps are used in this modeling only for their manning's value which was described in Chowmen's book (MeGRA & HItr). There are numerous aspects, which affect the value of Manning's n as well as surface roughness, vegetation, channel abnormalities, extent and nature of the waterway, seasonal fluctuations, suspended material and temperature.(Alzahrani, 2017) LULC map was imported into the HEC-RAS model and manning values were entered into the table. This map overlays the storage area and represents the land use and land cover in our study area.

2.5 HEC-RAS:

Hydrologic Engineering Centers-River Analysis System (HEC-RAS) published in 1995, is a unified bundle of hydraulic scrutiny program, in which the operator interacts with the system using the Graphical User Interface (GUI). This system is proficient at performing steady and unsteady flow and sediment transport and numerous other hydraulic design calculations. Results acquired from this model can be useful for flood hazard management and flood insurance researches (ShahiriParsa, Noori, Heydari, & Rashidi, 2016).

HEC-RAS developed by Hydrological Engineering Center, US Army Corps of engineers, which gives 1D Hydraulic analysis. HEC-RAS provide two types of modeling, 1) is 1D steady flow river and 2) is 1D and 2D unsteady hydraulic flow model (Wang, Yang, & Yao, 2012).

HEC-GeoRAS is an extension of ArcMap which creates the geometry file for flood processing in HEC-RAS from Digital Terrain Model (DTM) and executes further processing after the result export from HEC-RAS (Tahmasbinejad et al., 2012).

In the unsteady flow model, 2D hydrodynamic flow routing has been added HEC. 1D steady and 2D unsteady flow modeling in full saint Venant equations or Diffusion wave equation or 1D and 2D mutual model can be executed by regulars. 2D model can be run by adding elements of 2D flow area in the same way of storage area. A drawn polygon is added as 2D flow area then developed 2D computational mesh, after that link the 2D flow area to 1D model. 2D diffusion wave equation has more steadiness properties and lets the software work fast, whereas 2D full saint Venant equation is appropriate to broad arrays of complications. However by using the 2D diffusion wave equations, many modeling problems can be modeled correctly. 2D unsteady flow equation uses an implicit finite volume algorithm, it allows the bigger computational time steps than the explicit one. Finite volume method gives an improved measure of stability and steadiness above a finite component technique.

In HEC-RAS wetness and dryness of 2D elements are strong in the finite volume solution algorithm. 2D flow area can control the abrupt flash of water in an area if it started dried. This algorithm can also control mixed flow regimes (Brunner, 2014).

CHAPTER 3

Results and Discussions

1.1 Glacier change detection

Glacier change detection was done using the supervised classification method. Training samples were acquired by visual interpretation and Google earth imagery. Study area was divided into 5 general classes i.e. glacier, debris, water, vegetation, and open land. The analysis was temporal, for the years of 1994, 2002, 2009, 2013 and 2017, which shows continuous changes in each class. Our study area includes the four major glaciers of Hunza valley, along the KKH, and Passu and Hussaini village. Results of classification are shown in Figure 5, which is representing the classes of LULC and KKH. Detailed results showed decrease in glacial area of total study area. Glacial area was 27.34%, 28.4%, 27.74%, 25% and 23.81% of total study area in 1994, 2002, 2009, 2013 and 2017 respectively. The total decrease in glacial area was 3.53% from 1994 to 2017. This decrease shows the overall decrease of glacier area not of one specific glacier.

The study area is rich in glaciers; there are number of glaciers which are the source of freshwater for Pakistan's nation. If the glaciers continue to receding at this rate then it will be an alarming situation for the availability of freshwater to millions of people.

To analyze the difference in each glacier, comparison of classified result of 2017 tongue of each glacier with Global Land Ice Measurement from Space (GLIMS), glacier boundary was done. This comparison shows a decrease in three glaciers i.e. Batura, Passu, and Gulmit but an increase in Ghulkin Glacier. Comparison has shown in Figure 6. 1999 and 2007 show the tongue boundary of GLIMS whereas 2017 shown the classified boundary. Batura glacier has decreased from 1999-2017 to almost 600meters. Passu glacier has decreased to 230meters. Gulmit glacier also decreased to 50meters. But the Ghulkin glacier has been increased from 1999-2017 to 157meters in our study.

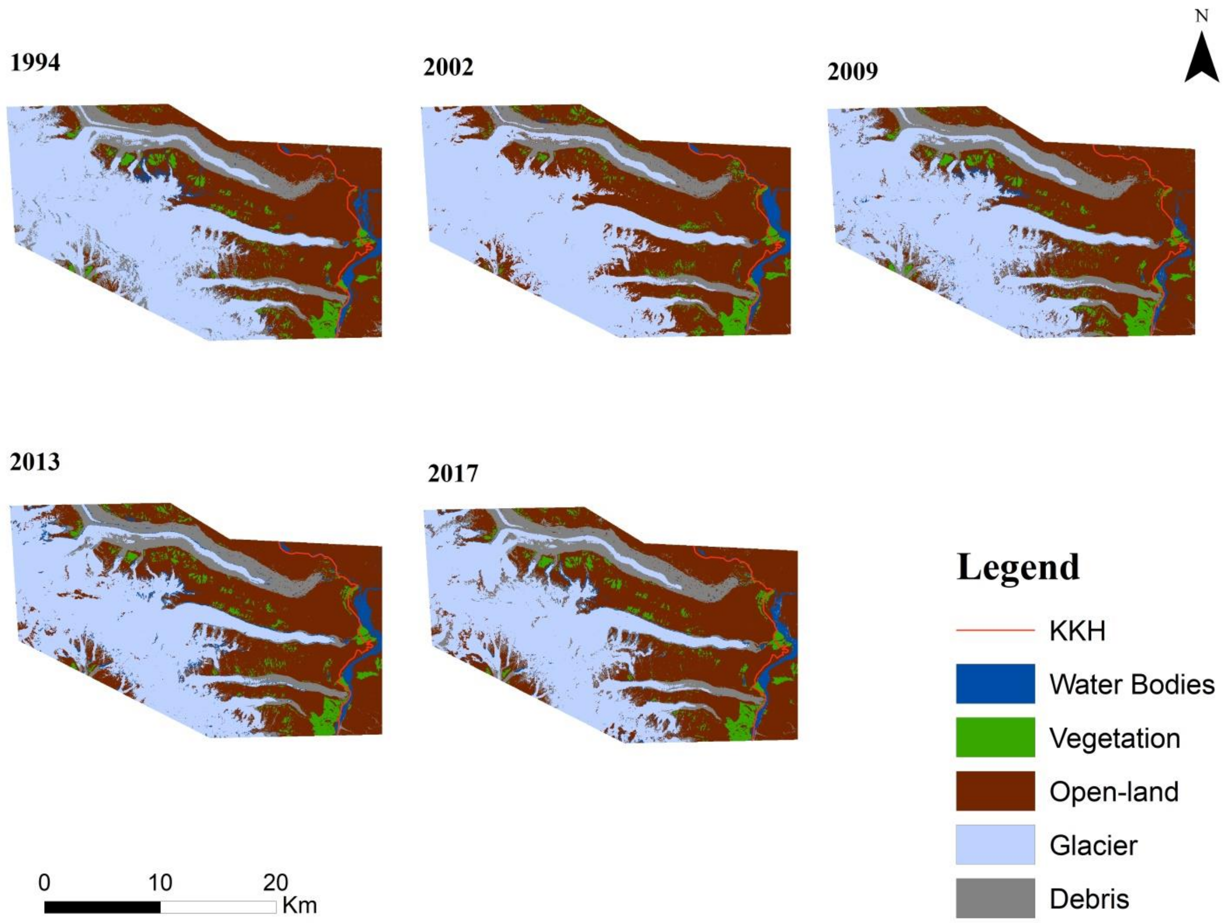

Figure 4. Supervised classification for the glacier change detection.

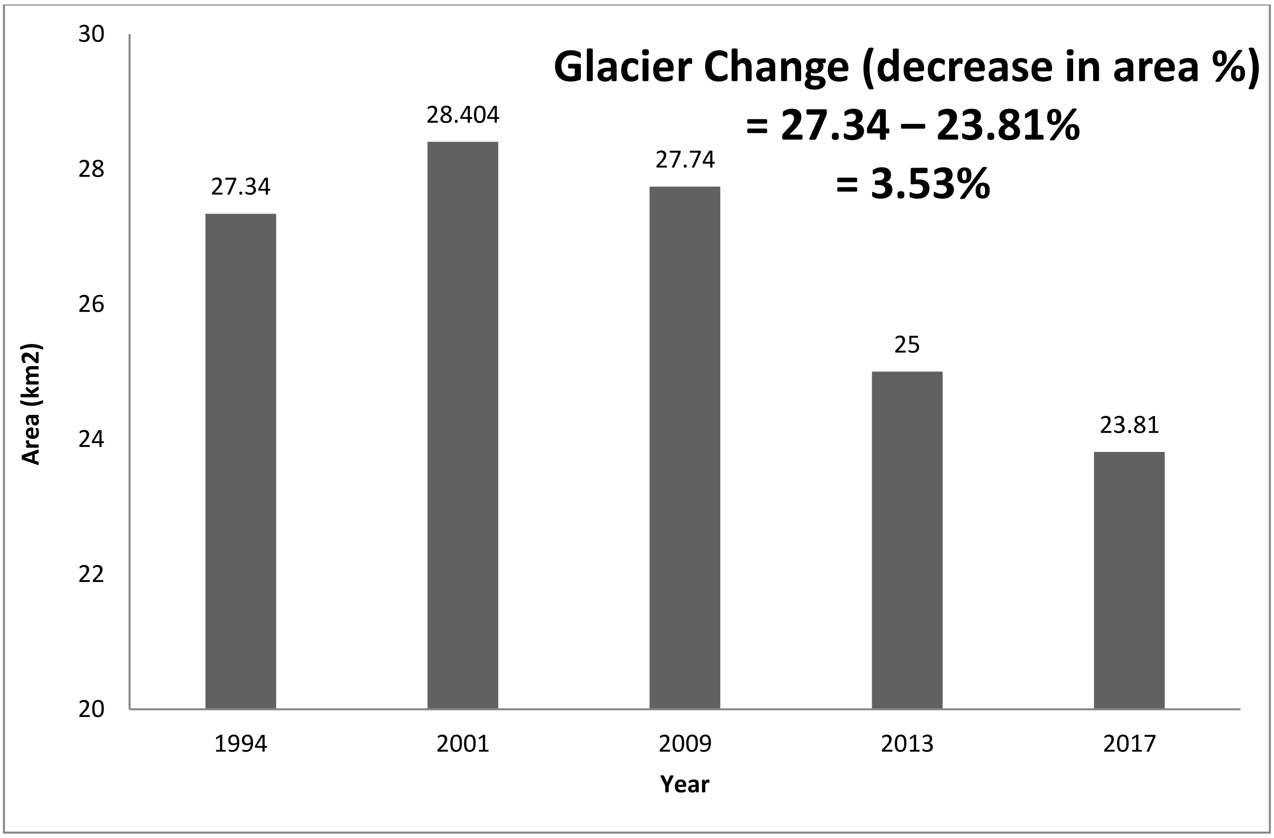

Figure 5. Glacial area change in percentage.

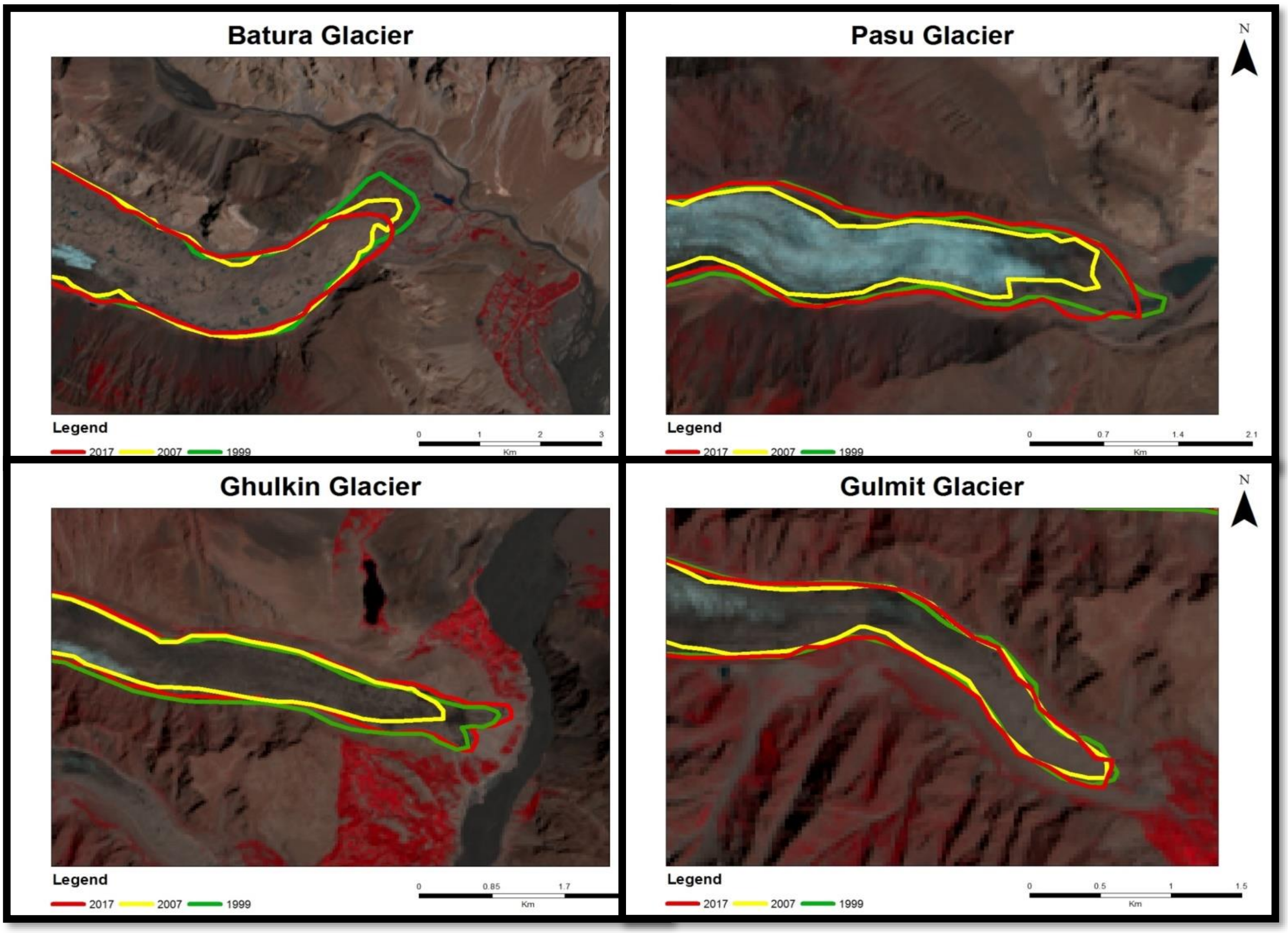

Figure 6. Comparison of glaciers boundary with GLIMS data.

Ghulkin glacier has been reported in past as an increasing glacier (Scherler et al., 2011). Karakoram region is well known for its surge-type glaciers, especially in the central Karakoram region, glaciers are surging rapidly. Hispar glacier is one of the surged type glaciers which are not surging by itself, but surging as an impact of surging of its tributaries (Copland et al., 2011).

Other three glaciers are decreasing not rapidly. But Passu glacier is receding toward up and may cause an increase in the area of lake which is present at its mouth. This lake remains frozen in most of the time of year but melts in some summer months and discharge its outflow into the Hunza river through its tributary which is crossing between the Passu village. Melting of whole lake or changes in glacier can cause an increased discharge which can lead to GLOF and can affect the downstream population and infrastructure. Passu lake has been already carried two GLOFs in last two decades and blocked the KKH and destroyed the infrastructure along Hunza river (Zaidi, Yasmeen, & Siddiqui, 2013).

3.1.1 Comparison with Climatic Data

To check the relationship of glacier change with climate, comparison of classified results with climatic data of Temperature and precipitation was done. The annual average temperature was acquired from Pakistan Meteorological Department (PMD) in℃ from 2007 to 2017 of Hunza station and 1995-2013 of Khunjerab station. Precipitation data were also acquired from PMD in mm from 2007-2017 and 1995-2013 of Hunza and Khunjerab station respectively.

Both stations are different in heights therefor their trends are different from each other. Hunza station is describing that temperature is increasing and rainfall is decreasing. In 2007 temperature was 11.78℃ which increased in 2017 and reached to 13.76℃, whereas precipitation in 2007 was 1mm which decreased in 2017 and reached to 0.22mm annual precipitation. From this climatic trend, it can be said that high temperature and decreasing precipitation is causing the depletion of glaciers but it should remain in mind that this station is in a bit low altitude than our study area. Therefore Khunjerab station data was also acquired, which is located at high altitude. The temperature in 1995, was-0.6℃ and increased in 2013 and reached to -0.4℃. and precipitation was 0.22mm and increased to 0.49mm in the years of 1995 and 2013 respectively. This trend is also showing an increase in temperature but also an increase in precipitation. In both station's results temperature and precipitation both are not uniformly increasing or declining, but the trend is uninterruptedly shifting.

Graphical representation of both stations is shown below in Figure 7&8. As the climate is changing, the temperature is increasing all over the world. According to the literature temperature is increasing with the rate of 0.32℃ -.0.34℃ per decade. Warming trends is change in Pakistan, in last 40 years 0.76℃, whereas in another high altitude region this increase was recorded to 1.5 ℃ (Chaudhry et al, 2009). Increase in temperature and persistence of heatwaves are the main causes for melting the glaciers and retreating of glaciers. But 35 glaciers are observed as proceeding and 11 are surging remarkably. These observations are causing an increasing number of glacial lakes (Rasul et al., 2011; Hewit et al., 2009).

3.2 Hydrodynamic Modeling

Glacier lake outburst flood (GLOF) modeling was done using HEC-GeoRas and HEC-RAS models. HEC-GeoRas is an extension of ArcMap to generate the geometry or layers for HEC-RAS and then import into HEC-RAS. After flood modeling in HEC-RAS, results again import into ArcMap to generate the maps. HEC-RAS 2D modeling was used in this study because it is freely available and can works directly with ArcMap. 2D modeling has advantages over 1D modeling; firstly it provides the capacity to simulate multi turning and multi-channel flows. Secondly it models great altitude of flow round waterway curves, turbulent eddying etc. These circumstances are the features of GLOF s so it is beneficial to model them. Additionally with 2D modeling, evaluating the individuals and infrastructure hazard is an easy task, and there is no requirement to incorporate the 1D modeling (Kougkoulos et al. 2018; Westoby et al. 2014).

A constraint of the HEC-RAS model is that, though it can model the sediment flow but it cannot model the debris flow which comes with GLOF (Wang et al. 2015).

Mesh was used for this study was 10*10 cell size, and for this study was GMRC hydrology data was used from 10th June 2011 to 14th August 2011 on a daily basis. This data was used because in summer season discharge of lake was high otherwise discharge in winter season was in negative value and negative values are not useful for us, and the data was not available for other days. Results were available in-depth and velocity, maps were generated in ArcMap. Comparison has been carried in this chapter between the GMRC data and our assumed data, which is an increment of 10% in original GMRC data Figure 9.

Any hydrologic and hydraulic modeling in the collaboration of GIS environment includes three steps; Pre-processing of data, Modeling stage and Post-processing of data. For pre-processing of data DEM of Passu village was used as a key input in order to create RAS layers like storage area, storage area was created using the polygon tool of digitization (Patel & Gundaliya, 2016)

In this study, layer of storage area was generated because 2D unsteady flow data modeling was used which can be done with or without cross-sections (Brunner, 2016). 2D unsteady flow analysis was run, with starting date of 10th June 2011 to end date of 11th August 2011. The computational setting of our model was as follows; computational interval was 1 minute, mapping output interval 1 day, hydrograph output interval was 1 day and detailed output

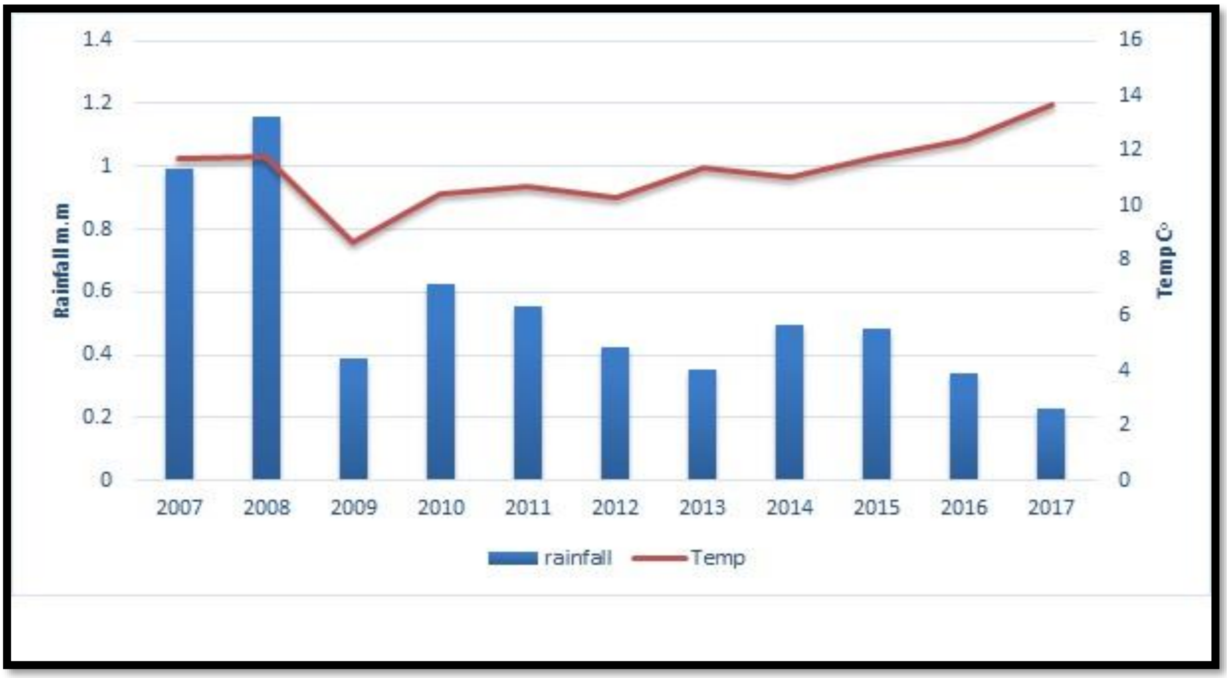

Figure 7. Average annual climatic data of Hunza station.

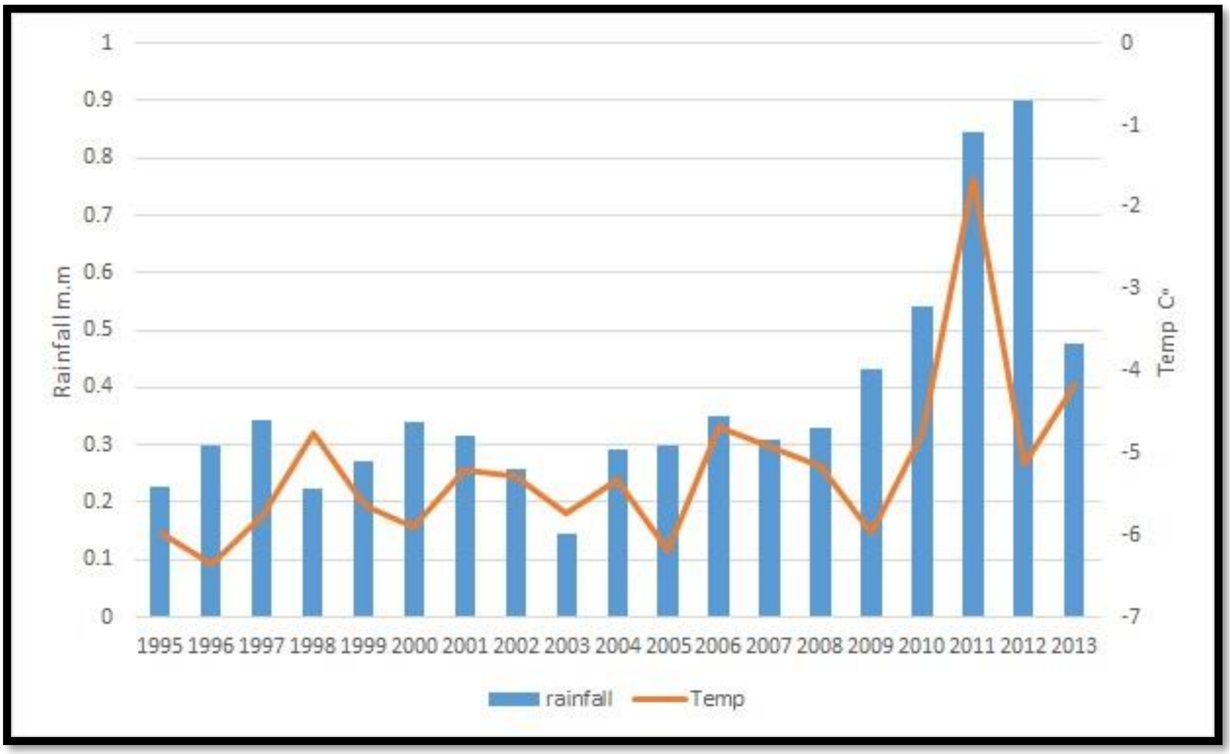

Figure 8. Annual average climatic data of Khunjerab station.

interval was also 1 day. Full momentum equation and diffusion wave both were tested for our study area but best results were shown by full momentum equation

Therefore this equation was used for both datasets. In diffusion wave equation pixels in results were not continuous, they were irregular and representing the false image of flood.

Results of the model were in depth and velocity. As in this study two datasets were used, there is minor difference between datasets result. In both datasets, depth is high in-stream center same as velocity Figure 10&11. Velocity is also classified into three classes i.e. low, medium and high. There are minor differences between two dataset's results. In Figure 3, original dataset, depth of flood is approximately 6.5 meter, which has been increased in self-prepared data to 6.74meter. In both datasets result flood depth is high the in-stream center and low depth on sideways of the stream. Flood water will fall in Hunza River which is flowing to Gilgit.

Area of lake plays an important role in GLOFs phenomenon; therefore observation of Passu lake was done. Passu Lake is not a constant in area but changing its area according to seasons. Observed results shows that the lake area, by Google Earth imagery, increases its area in winter seasons whereas expands its area in summer seasons. In winter the lake is frozen and the discharge of lake is in negative values.

Few buildings are near to stream as seen it from Goggle earth imagery; field trip was not done because of shortage of funding. To elaborate our study and explain research's results, pixels of flood inundated maps were counted for both data sets result. Table 4, is showing the pixels counting in flood depth classes and flooded area in percentage %. In original data total flooded pixels are 739, on the other side in self-prepared data pixels have been increased to 747. The area in percentage is increasing in flooded area; in original data area in percentage are 54.26%, 28.55% and 17.18% for the classes of low, medium and high respectively. And in increment data, area in percentage was 51.27%, 29.77% and 19% for low, medium and high respectively.

Change in the area has been observed for each class, in low class area is decreased which is -2.99% and in medium and high class area has been increased to 1.16% and 1.82% respectively.

It can be seen in results that flow depth and flow velocity is high in the main channel as compare in floodway. In flood classes (low, medium and high) pixels are increasing, as per it can assume that if original flow data increases then the pixels of flooded area will automatically increase and can cause a major disaster to the study area. In this study Karakoram bridge have not modeled because in 2D modeling bridges cannot be modeled.

Pixels are actually showing the area and width of the inundated area. Water is spreading as it approaches stream mouth or where it discharged in Hunza River because elevation is declining there. According to the results, flood is not severe enough to make a hazardous situation because flood values are high the in-stream center and no built-up area is found there. If GLOF again happened in this area then the results will not be same as this study's result because this study is not showing a real GLOF scenario. However, the results of this study can be beneficial to make estimation for any GLOF happen here and to estimate the destruction made by GLOF and to mitigate the hazard and save people of this area.

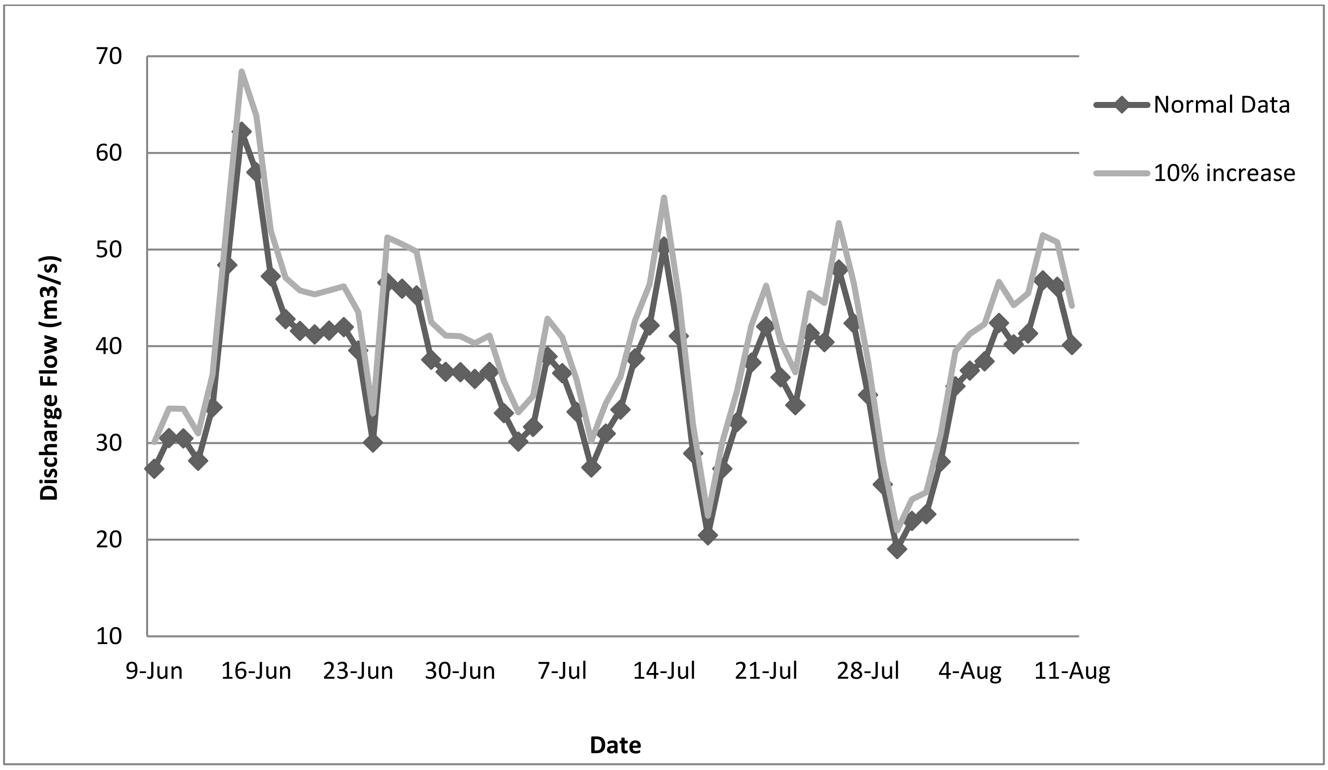

Figure 9. Comparison of GMRC data and data with increment.

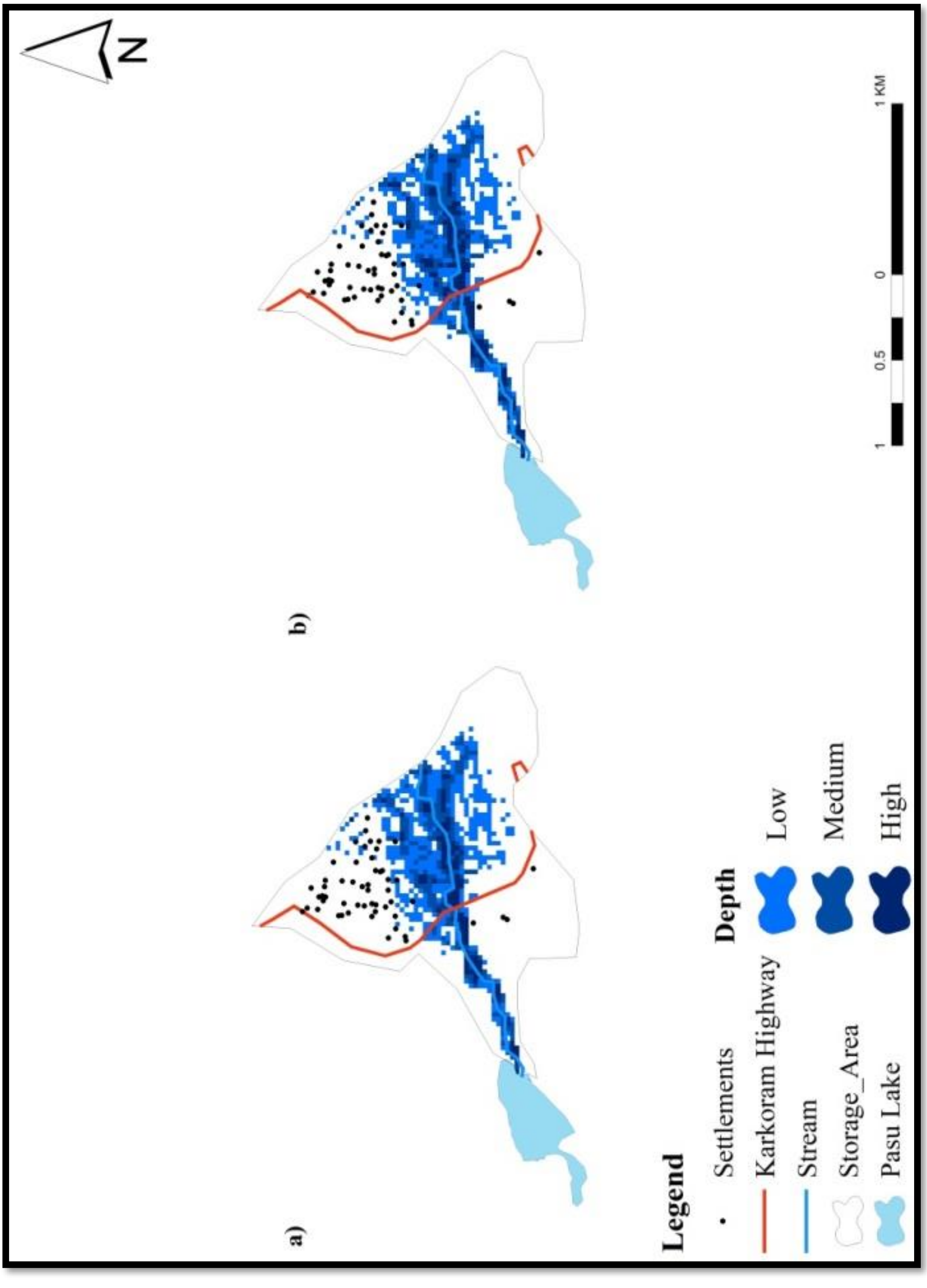

Figure 10**.** Flood Depth of a) GMRC dataset; b) increment dataset.

Table 3**.** Flooded area in percentage and change in flood area.

Depth	**Original data pixels**	**Flooded area in %**	**Pixels of Data with 10% increment**	**Flooded area in %**	**Change in flooded area in %**
Low	401	54.26%	383	51.27%	-2.99%
Medium	211	28.55%	222	29.71%	1.16%
High	127	17.18%	142	19%	1.82%
Total	739	100%	747	100%	

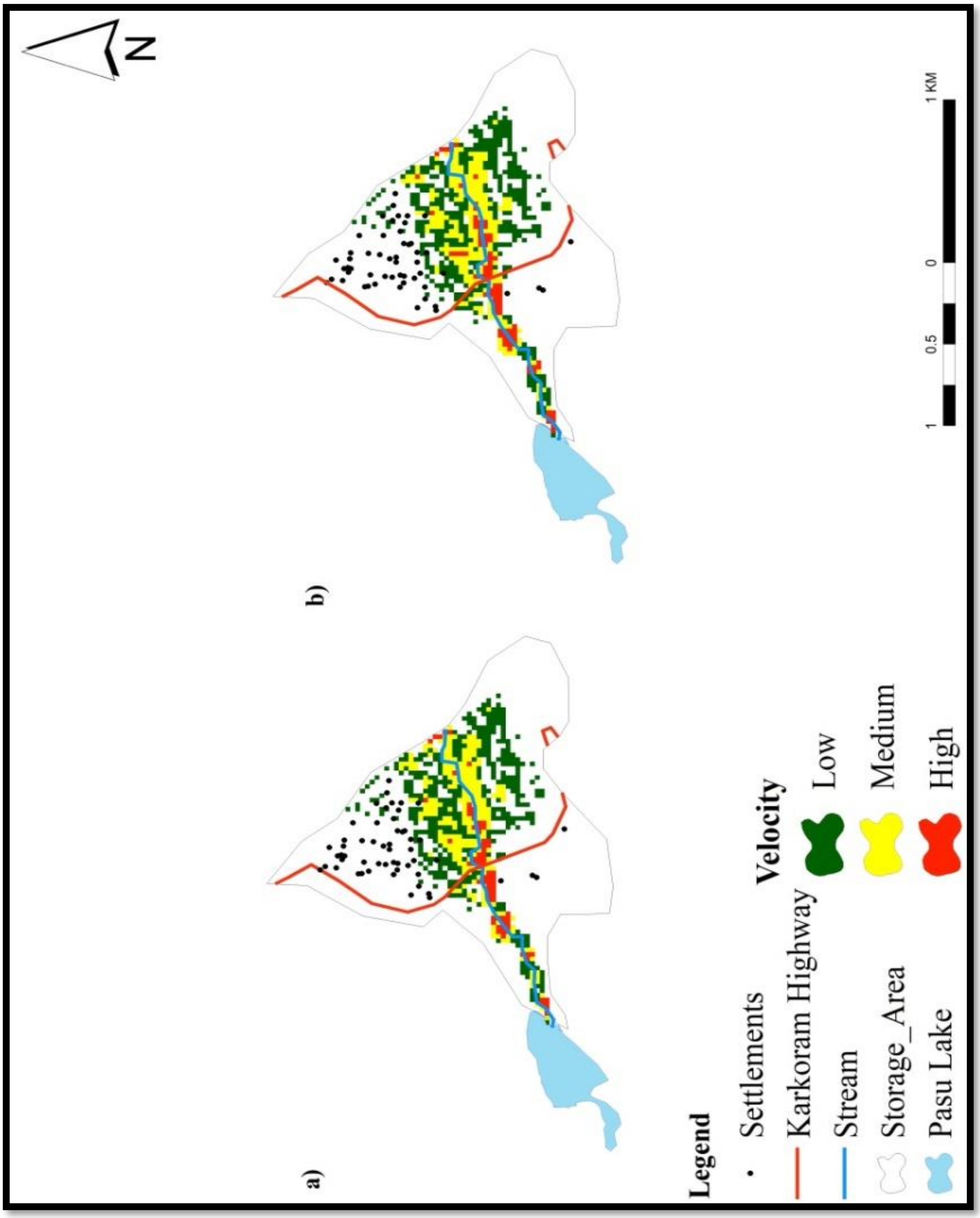

Figure 11. Flood velocity of a) GMRC dataset; b) increment dataset.

Chapter 4

Conclusion

This study includes the temporal change detection of Batura, Passu, Gulmit, and Ghulkin glaciers along the KKH. These glaciers are along the KKH; therefor they have impact on CPEC. Temporal change detection was carried with the help of Remote Sensing (RS) and Geographical Information System (GIS) techniques. Landsat 5 and 8 images were used, for the years of 1994, 2002, 2009, 2013 and 2017. Supervised classification was applied to assess the temporal change of glaciers. Results of supervised classification depict that these glaciers are continuously changing especially from their tongue. Three glaciers i.e. Batura, Passu, and Gulmit are receding upwards, whereas Ghulkin glacier is increasing. Overall the area of glaciers has been decreased. The total area of the study area was converted into sq.km, and the area of glaciers has been decreased to 3.53% of total study area.

One comparison was done to assess the change in glaciers. GLIMS glacier boundary data was used to analyze the change in glacier tongues. 1999 and 2007 were the data of GLIMS, whereas 2017's boundary of glaciers was acquired from supervised classified result. Results of this comparison show that Batura, Passu, and Gulmit glacier has been receded to 0.596, 0.23 and 0.05km respectively from 1999 to 2017, whereas, Ghulkin glacier has increased to 0.157km in 1999-2017 time span.

Glacier change detection results then compared to climatic data, i.e. Temperature and Precipitation. Climatic data were acquired from Hunza and Khunjerab station from 2007-2017 and 1995-2013 respectively. Both stations show an increase in temperature, which is -0.02℃ and 1.98℃ for Khunjerab and Hunza station respectively. This increase in temperature can conclude that this is a factor of glacier changing and causing them to retreat. Precipitation is decreasing in Hunza station and increasing in Khunjerab station.

To analyze the GLOF, hydrodynamic modeling has been done via HEC-RAS 5.0.5. HEC-RAS is a vast model and useful to model the GLOF. GLOF is an emerging hazard for Pakistan because climate change is affecting the glaciers of Pakistan than other glaciers all-over the world. Hydrology data was acquired from GMRC and one assumed data which is an increase of 10% in original data was used. Increment data was used because, there was not available the actual flood data; therefore assumed data was used for this study.

The 2D unsteady model was run to assess the GLOF. The 2D storage area was drawn in HEC-GeoRas, which is an extension of ArcMap. Results of model were in the form of flood Depth and Velocity. Maximum depth for original data was 6.5 meters and for assumed data it was increased to 6.74meters. To analyze the flood inundated area calculation of the pixels of flooded area. Inundated pixels for the original data were 739 whereas it increased in assumed data to 747 pixels. HEC-RAS 2D modeling was done for this study area because it was not done in this study area before. The area in percentage is increasing in flooded area; in original data area in percentage are 54.26%, 28.55% and 17.18% for the classes of low, medium and high respectively. And in increment data, area in percentage was 51.27%, 29.77% and 19% for low, medium and high respectively.

Change in the area has been observed for each class, in low class area is decreased which is -2.99% and in medium and high class area has been increased to 1.16% and 1.82% respectively. The results of this study can be helpful for the hazard mitigation organizations and can be done this study using more accurate datasets. This study was done using the RS&GIS techniques, which shows the importance of these techniques in hazard management and mitigation processes.

REFERENCES

1. Alzahrani, A. S. (2017). *Application of Two-Dimensional Hydraulic Modeling in Riverine Systems Using HEC-RAS.* University of Dayton,
2. Anwar, Y., & Iqbal, J. (2018). Spatio temporal change of selected glaciers along karakoram highway from 1994-2017 using remote sensing and GIS techniques. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 3*.
3. Ashraf, A., Naz, R., & Roohi, R. (2012). Glacial lake outburst flood hazards in Hindukush, Karakoram and Himalayan Ranges of Pakistan: implications and risk analysis. *Geomatics, Natural Hazards and Risk, 3*(2), 113-132.
4. Bajracharya, B., Shrestha, A. B., & Rajbhandari, L. (2007). Glacial lake outburst floods in the Sagarmatha region. *Mountain Research and Development, 27*(4), 336-345.
5. Bishop, M., & Shroder, J. F. (2004). *Geographic information science and mountain geomorphology*: Springer Science & Business Media.
6. Bishop, M. P., Olsenholler, J. A., Shroder, J. F., Barry, R. G., Raup, B. H., Bush, A. B., . . . Haeberli, W. (2004). Global Land Ice Measurements from Space (GLIMS): remote sensing and GIS investigations of the Earth's cryosphere. *Geocarto International, 19*(2), 57-84.
7. Brunner, G. W. (2014). Combined 1D and 2D Modeling with HEC-RAS. *Hydraulic Engineering Center, US Army Corps of Engineers*.
8. Brunner, G. W. (2016). HEC-RAS, River Analysis System Hydraulic Reference Manual.
9. Chaudhry, Q. U. Z., Mahmood, A., Rasul, G., & Afzaal, M. (2009). Climate change indicators of Pakistan. *PAkistan Meterological Department*.

10. Din, K., Tariq, S., Mahmood, A., & Rasul, G. (2014). Temperature and precipitation: GLOF triggering indicators in Gilgit-Baltistan, Pakistan. Pakistan Journal of Meteorology, 10(20).
11. Geografii, I., & Kotliakov, V. M. (1997). *World Atlas of Snow and Ice Resources [cartographic Material]*: Moscow: Russian Academy of Sciences, Institute of Geography.
12. Goudie, A. (1981). Fearful landscape of the Karakoram. *The Geographical Magazine, 53*(5), 306-312.
13. Hewitt, K. (2005). The Karakoram anomaly? Glacier expansion and the 'elevation effect,'Karakoram Himalaya. *Mountain Research and Development, 25*(4), 332-341.
14. Hewitt, K. (2009). Rock avalanches that travel onto glaciers and related developments, Karakoram Himalaya, Inner Asia. *Geomorphology*, *103*(1), 66-79.
15. Hewitt, K. (2011). Glacier change, concentration, and elevation effects in the Karakoram Himalaya, Upper Indus Basin. *Mountain Research and Development, 31*(3), 188-201.
16. Immerzeel, W. W., Droogers, P., De Jong, S., & Bierkens, M. (2009). Large-scale monitoring of snow cover and runoff simulation in Himalayan river basins using remote sensing. *Remote sensing of Environment*, *113*(1), 40-49.
17. Immerzeel, W. W., Pellicciotti, F., & Shrestha, A. B. (2012). Glaciers as a proxy to quantify the spatial distribution of precipitation in the Hunza basin. *Mountain research and development*, *32*(1), 30-39.
18. Jain, S. K., Lohani, A. K., Singh, R. D., Chaudhary, A., & Thakural, L. N. (2012). Glacial lakes and glacial lake outburst flood in a Himalayan basin using remote sensing and GIS. *Natural hazards*, *62*(3), 887-899.

19. John F. Shrouder, J., Michael P. Bishop. (1998). Glaciers of Pakistan. In *Satellite image Atlas of Glaciers of the world* (pp. 1 3 8 6 -F- 4): US Government Printing Office.

20. Kougkoulos, I., Cook, S. J., Edwards, L. A., Clarke, L. J., Symeonakis, E., Dortch, J. M., & Nesbitt, K. (2018). Modelling glacial lake outburst flood impacts in the Bolivian Andes. *Natural Hazards, 94*(3), 1415-1438.

21. Mayewski, P. A., & Jeschke, P. A. (1979). Himalayan and Trans-Himalayan glacier fluctuations since AD 1812. *Arctic and alpine research, 11*(3), 267-287.

22. MeGRA, W., & HItr, C. E. S. OPEN-CHANNEL HYDR~ AULICS.

23. Miller, J. D., Immerzeel, W. W., & Rees, G. (2012). Climate change impacts on glacier hydrology and river discharge in the Hindu Kush–Himalayas. *Mountain Research and Development, 32*(4), 461-468.

24. Miller, K. J. (1984). *The international Karakoram project* (Vol. 1): Cambridge University Press.

25. Musofer, A. R. (2010). Glacier advancement hazards and its effect on local community: A case study of Hussaini, Hunza. *Journal of Himalayan Earth Sciences*, *43*, 64-65.

26. Patel, C. G., & Gundaliya, P. J. (2016). Floodplain Delineation Using HECRAS Model—A Case Study of Surat City. *Open Journal of Modern Hydrology, 6*(01), 34.

27. Paul, F., Winsvold, S., Kääb, A., Nagler, T., & Schwaizer, G. (2016). Glacier remote sensing using sentinel-2. Part II: mapping glacier extents and surface facies, and comparison to Landsat 8. *Remote Sensing, 8*(7), 575.

28. Raj, K. B. G., Remya, S., & Kumar, K. V. (2013). Remote sensing-based hazard assessment of glacial lakes in Sikkim Himalaya. *Current Science*, 359-364.

29. Rankl, M., Vijay, S., Kienholz, C., & Braun, M. (2013). Glacier changes in the Karakoram region mapped by multi-mission satellite imagery. *Cryosphere Discuss, 7*(4), 4065-4099.

30. Rasul, G., Chaudhry, Q., Mahmood, A., Hyder, K., & Dahe, Q. (2011). Glaciers and glacial lakes under changing climate in Pakistan. *Pakistan Journal of Meteorology, 8*(15).

31. Shakoor, A., & Ejaz, N. (2019). Flow Analysis at the Snow Covered High Altitude Catchment via Distributed Energy Balance Modeling. *Scientific reports*, *9*(1), 4783.

32. Scherler, D., Bookhagen, B., & Strecker, M. R. (2011). Spatially variable response of Himalayan glaciers to climate change affected by debris cover. *Nature geoscience, 4*(3), 156.

33. ShahiriParsa, A., Noori, M., Heydari, M., & Rashidi, M. (2016). Floodplain zoning simulation by using HEC-RAS and CCHE2D models in the Sungai Maka river. *Air, Soil and Water Research, 9*, ASWR. S36089.

34. Shroder Jr, J., Dimarzio, C., Bussom, D., & Braslau, D. (1978). Remote sensing of Afghanistan. *Afghanistan Journal*, *5*(4), 123-128.

35. Shukla, A., Gupta, R., & Arora, M. (2009). Estimation of debris cover and its temporal variation using optical satellite sensor data: a case study in Chenab basin, Himalaya. *Journal of Glaciology, 55*(191), 444-452.

36. Tahmasbinejad, H., Feyzolahpour, M., Mumipour, M., & Zakerhoseini, F. (2012). Rainfall-runoff Simulation and Modeling of Karon River Using HEC-RAS and HEC-HMS Models, Izeh District, Iran. *Journal of Applied Sciences(Faisalabad)*, *12*(18), 1900-1908.

37. USACE. (2016). HEC-RAS River Analysis System Hydraulic Reference Manual. Version 5.0. In: Institute of Water Resources, Hydrological Engineering Center Davis.

38. Wang, W., Yang, X., & Yao, T. (2012). Evaluation of ASTER GDEM and SRTM and their suitability in hydraulic modelling of a glacial lake outburst flood in southeast Tibet. *Hydrological Processes, 26*(2), 213-225.

39. Westoby, M. J., Glasser, N. F., Brasington, J., Hambrey, M. J., Quincey, D. J., & Reynolds, J. M. (2014). Modelling outburst floods from moraine-dammed glacial lakes. *Earth-Science Reviews, 134,* 137-159.

40. Williams, R. S., & Ferrigno, J. G. (1998). *Satellite image atlas of glaciers of the world*: US Government Printing Office.

41. Yao, T. (2008). Map of Glaciers and Lakes on the Tibetan Plateau and Adjoining Regions 1: 2000000. *Xi ✗an Cartographic Publishing House*.

42. Zaidi, A. Z., Yasmeen, Z., & Siddiqui, M. D. (2013). *Glacial Lake Outburst Flood (GLOF) risk mapping in Hunza River Basin (Pakistan) using geospatial techniques.* Paper presented at the 2013 6th International Conference on Recent Advances in Space Technologies (RAST).\