Estimation of Glacier Equilibrium Line Altitude in the Hunza River Basin of Northern Karakoram, Pakistan

MASTER OF PHILOSOPHY

In

Environmental Science

By

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Registration No: 02312013004

Supervised by: Dr. Abida Farooqi

Department of Environmental Sciences

Faculty of Biological Sciences

Quaid-i-Azam University, Islamabad

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QUAID-I-AZAM UNIVERSITY
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A Thesis Submitted in Partial Fulfilment of theRequirement for the Degree

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DEDICATION

I dedicate this thesis to my beloved grandparents, parents, siblings, and a supervisor who have been always a source of inspiration for me and stood beside me at every moment in my life.

CERTIFICATE OF APPROVAL

It is to certify that the research work presented in this thesis, entitled **"Estimation of glacier Equilibrium line Altitude in the Hunza River Basin of northern Karakoram, Pakistan"** was conducted by **Mr. Sabih Ud Din** (Reg. No. 02312013004) under the supervision of **Dr**. **Abida Farooqi.** No part of this thesis has been submitted elsewhere for any other degree. This thesis is submitted to the Department of Environmental Sciences, in the partial fulfillment of the requirements for the degree of **Master of Philosophy (M.Phil.)** in the field of Environmental Sciences, Quaid-i-Azam University, Islamabad.

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Sabih Ud Din

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List of Abbreviations

AABR	Accumulation Area Balance Ratio
AAR	Accumulation Area ratio
CC	Climate Change
ELA	Equilibrium Line Altitude
GIS	Geographic Information System
HI	Hypsometric Integral
HKH	Hindukush Karakorum Himalaya
HRB	Hunza River Basin
RS	Remote Sensing
SRTM	Shutter Radar Topography Mission

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Abstract

Hunza River Basin (research region) in the Karakoram Himalaya is distinctive for a variety of reasons. Firstly, the glaciated areas have a greater mean altitude as compared to other glaciated landscapes in the Karakoram, Secondly, the basin is occupied by both debris and clean ice glaciers. Thirdly, the glaciated region is more vulnerable to the mountain communities living downstream. It is very crucial to comprehend the strength of the topography or morphology of the surface and the likely effects of changing glacial ice, which can alter how material is transported from higher to lower elevations. For those living downstream, the ice masses and snow of the Hunza River Basin (HRB) provide a vital source of fresh water. These readily available ice and snow masses are significantly impacted by changing climatic conditions. There are many kinds of glaciers in Pakistan's Karakoram region like Alpine or valley glaciers. Due to climate change, these glaciers may have an impact on the population living downstream through avalanches and surge occurrences. Therefore, it is crucial to monitor the glaciers. Equilibrium line altitude (ELA) is a measure of mass balance. Due to the rough terrain covered in glaciers and the paucity of climate data above 5000 masl, field measurements for the measurement of ELA of most of the Karakorum glaciers are not easily accessible. However, in this study we used the hypsometrically controlled accumulation area ratio AAR (0.6) and accumulation area balance ratio AABR (2.24) techniques to estimate ELAs and reconstruct the relation between climate and glacier data in the Hunza River Basin of the Karakoram region. This method adjusted glacier geometry (area) to future ELA shifts by applying recommended AAR rather than constant glacier area. Batura Glacier's geometry was altered by 32% by a 380m ELA decrease from 5049-4668 m with a steady AAR of 0.6-0.45. The biggest losses in glacier-ice area are anticipated for top-heavy glaciers (Hisper, Batura and Kukuar), whose expected geometrical losses are widely varied. It is determined that the reconstructed three-dimensional glacier surfaces have a significant impact on the quality of ELAs.

Chapter 1

Introduction and Literature Review

Climate change (CC) is a natural phenomenon but due to human intervention the rate at which it changes is happening more drastically as compared to natural pace which is ridiculous and alarming. Climate change is described as “change in climate which is caused directly or indirectly to human activity that alters the composition of the global atmosphere which is in addition to natural climate variability observed over comparable time periods” (UNFCCC, 1994). Furthermore, climate variability means alteration in the mean ambient state of the atmosphere for a long time, which creates abnormalities in climatic features, which are measurable like temperature, wind pattern, precipitation, and storms. The IPCC mentioned that during the last decade, the normal worldwide temperature has expanded by 0.6 °C since mechanical insurgency, which alters the worldwide normal temperature is anticipated within the range of 1.4°C - 5.8°C in the 21 Century (IPCC 2001). Generally, Climate Change is defined as change in the "average weather conditions in a particular area over a long period of time" (more than 30 years and so on). According to IPCC, the most unpredictable risk for mountain communities around the world, related to climate change are floods, avalanches, forest fires and landslides. These extremes are becoming more common in mountainous areas and threatened livelihood by enhanced water losses due to change in precipitation and evaporation patterns (IPCC, 2001).

Furthermore, many mountain people depend upon agribusiness for their employments, but climate change seems to have an unfavourable effect on cultivating. Water systems will be influenced, to begin with by floods and after that by drought seasons, making survival harder for subsistence agriculturists as well as those who develop cash crops both in these mountain areas as well as within the lower catchments. Life for most mountain individuals will indeed get harder with the coming changes in climate and uncertainty because it will anticipate encouraging disrupt mountain surrounding. The affectability of mountain environments to climate change is especially utmost because of their delicate nature, geography, soak slopes, and differences of biological systems. For illustration, mountains will end up more perilous as rising temperatures increases dissolved permafrost and frigid run-off that in turn will quicken soil disintegration as well as the probability of falling rocks, avalanches, surges, and torrential slides. Extreme events or hazards are predicted to end up increasingly common. Warming patterns will also force numerous species to emigrate though in appearance for habitat and mountain individuals as well people will need to adjust to changes – or take off their homes as conventional sources of food and fuel grow scarce (Hussain *et al*., 2005).

Climate change has been influencing the glaciated environment and it is causing the retreat of glaciers worldwide. However, the glaciers extent in Hindukush -Karakorum and Himalayan region (HKH) has remained under discussion because glaciers are retreating and advancing in this region (Karakorum Anomaly) (Akhter *et al*., 2008). Glaciers are complex bodies that provide vital fresh water for agriculture, electricity, and for household use etc. To make certain future financial progress and better-quality lifestyles of the people living downstream, water supplies from glaciers in Asia's mountainous region must be carefully utilised. (Sher Muhammad *et al*.,2016). Given the fact that the Karakoram glaciers and Himalayan only account for a little portion of whole global ice stocks, they provide excess amount of water more than 20% of the world's Population (Kaser, *et al*., 2010; Smakhtin *et al*., 2004; Hewitt, 2005). In a nutshell, climate change has many negative impacts like in capital terms as well as agriculture, health, water resources etc. (; Nkurunziza and Pilz, 2011; Archer, 2003; IPCC, 2007; Amorim *et al*., 2014; Devkota *et al*., 2014).

As we have studied that glacier are used as indicators of climate change (Bashir, 2020). There's presently considerable prove that ice sheets in the high mountains are dissolving owing to increases in temperatures within the highland and mountainous ranges, and if this continues, numerous of the world's mountain ice sheets will have become extinct completely by the end of this century. (Global Mountain Summit, 2002).

Agriculture, the economy, hydropower potential and human life is entirely reliant upon the availability of freshwater (Hazel & Wood, 2008; IPCC, 2014). This valuable resource has been subjected to constant variation due to climatic changes and global warming, but also anthropogenic activities have added more demand and pressure on it (Cisneros *et al*., 2014). Having profound knowledge about cryosphere dynamics and future alterations is very impertinent to all communities particularly to glacierized and high mountain areas, where community is utterly dependent upon melt water during dry and drought periods (Lutz *et al*., 2014; Bolch *et al*., 2017).

As we know that, glacial ice covers about 10% of earth's land surface including the ice sheets and ice caps of Antarctica and Greenland. Glaciers store 69% of fresh water and covers an area of 15 m Sq/m (National Snow and Ice data Centre, 2020). Glaciers are very significant and are essential component of the hydrological cycle upsetting the water balances on spatial scales. They are potent indicator of climate change and thus contributing to rise in sea level in response to global warming. On regional and local scale, glaciers serve as reservoirs of freshwater thus contributing to seasonal river flows during the summer period and have impertinent implications for downstream water supplies, hydroelectricity production, supporting sustainable agriculture, forest-based livelihood (Immerzeel *et al.,* 2010; Hussain *et al.,* 2011).

1.1. Impact of Glaciers in HKH region:

Furthermore, glaciers have been present in the Hindukush Karakorum Himalaya (HKH) region since last ice age. HKH region is the most strongly glacierized in the world excepting the polar region (ICIMOD, 2018). This region offers the best place for global atmospheric circulation, exquisite biodiversity, vital water resources and the source of the world's largest rivers. However, due to climate crisis, glaciated regions are affecting badly, and it is causing the retreat of glaciers worldwide (Quincey *et al.,* 2014; Azam *et al.,* 2018). The global mean temperature has been enhanced by 0.85°C since 1980 and warming would continue to 3.7°C if greenhouse gas emissions stay on their current path according to 5th Assessment Report of the intergovernmental Panel on Climate Change (IPCC, 2013). However, the glaciers extent in Karakorum has remained constant since the 1970's and several reports have indicated that glaciers are advancing. The retreat or advance of glaciers in most areas of HKH has resulted in the formation, growth, and disappearance of glacial lakes (Gardelle *et al*., 2013; Rankl *et al*., 2014). Glaciers in Pakistan are receding at a level of 40-60 meters per decade because of climate change induced glacier recession (UNDP, 2017; Anwar & Iqbal, 2018). Unprecedented increase in glacier melt is not only plummeting ice mass but also enhancing the volume and extent of glacial lakes. The frequency of glacial hazards has been amplified because of an alarming temperature trend in Northern Pakistan (Rasul *et al.,* 2011).

As discussed above, the HKH region occupies a more glaciated region up to 36.8% area is under glaciation and 10% is covered by debris. Moreover, mountains in Pakistan occupy different types of glaciers (e.g. valley, cirque, snow fed glaciers, snow and ice avalanches nourished) and different micro climatic conditions(Baig & Muneeb, 2021). Most high elevated areas occupy water as snow and/or glaciers, resulting in an area of bewildering hydroclimate fluctuations. However, the HKH region are often referred to as Asia's water towers. Furthermore, the HKH region boasts an estimated 60,000 km2 of glaciers and is home to the world's greatest permanent land ice sheet. Beside the north and south poles, the HKH region is recognized as the Earth's third Pole, providing ecological services that support the livelihoods of 210 million people. Mostly, the HKH region contains the most convoluted landscape in the world, and it has a significant impact on the east Asian monsoon and worldwide atmospheric circulation too. Mountainous settings and a diversity of regional weather conditions characterise the Hindu Kush Himalayan (HKH) region. The HKH's high-altitude zones have experienced recent warming effects, particularly through the global warming hiatus. Rapid warming causes solid state water (snow, ice, glaciers, and permafrost) to decrease, resulting in a rise in meltwater, and more frequent flash floods, landslides, livestock diseases, and other disasters have been observed in the HKH region.(You *et al.*, 2017). Climate change may cause overall glacier mass to diminish, resulting in increased meltwater input to downstream river flows, especially during rapid warming seasons. Climate change and glacier retreat have caused several glacier lakes in the HKH region that are increasing dramatically.(Wang *et al.,* 2015). Decrease in winter precipitation causes glacial ice to be vulnerable to melting for extended periods of time, resulting in less accumulation and a loss of glacial mass. Owing to the sheer boost in temperature and decrease in the accumulation precipitation period, worldwide glaciers are showing a startling loss in mass balance. In comparison to the eastern Himalayas, the Karakoram–Hindukush glaciers are a least susceptible to climate change(Hewitt, 2005) However, they act differently as a result of their distinct responses to global warming related to other parts of the world.(Fowler & Archer, 2006; Sarikaya *et al.*, 2012, 2013) claim that eastern Himalayan glaciers are diminishing while progressing(advancing) in the Karakoram is more common (the so-called Karakoram Anomaly) but Speed of retreat, melting and stability of glaciers is uncleared (Scherler *et al.*, 2011). The temperature of Karakorum mountainous regions has remained out of phase with hemisphere temperature patterns for at least the last five centuries, showing that the Karakoram Anomaly is not a latest occurrence.

However, current changes in climate patterns are anticipated to have a significant impact on these glaciers and ice stocks, even if the degree of that impact is not yet known (Baig *et al.*, 2018). The Karakoram-Hindukush glaciers are less susceptible to climatic extremes in contrast to eastern Himalayan glaciers (Hewitt, 2005). According to the recent research in eastern Himalayan, glaciers are retreating rapidly whereas there is continuous increase in Karakorum glaciers (Karakorum anomaly) (Sarikaya *et al*. 2012, 2013). According to forecasts, roughly a 1/4th of the worldwide ice stocks might be wiped out by 2050, and half by 2100. Moreover, In the current Intergovernmental Panel on Climate Change (IPCC) assessment, by the end of the century (2077-2100), most of glaciers in the Asia High Mountain Range could lose around 64± 5% percent of their volume relative to the study periods of 1996-2015 according to the RCP 8.5 scenario. As a result, It is necessary to oversee the status of glaciers throughout the year for further precise analysis and improved forecasting of their volumetric variations.(Garg *et al.*, 2021). Furthermore, within the Karakoram–Hindukush, the Indus River Basin has the most snow, glaciers, and permafrost, providing water to Pakistan's 200 million inhabitants. As a result, the Indus relies heavily on meltwater from these glaciers and snow, as well as a rising downstream population. There are 54000 glaciers in the HKH region, Pakistan hosts 5218 glaciers covering 15041 km2 of ground area. Due to rugged terrain and unavailability of the resources there are uncertainties in data above 5000 masl because of meteorological stations locate in valleys cannot be reflected as representatives of such elevated heights locations, due to the fact that climatic data from these stations usually overestimate or underestimate precipitation. (Baig *et al*., 2018). Pakistan has 108 peaks over 6000 metres and more peaks over 5000 and 4000 metres. Five of the world's fourteen highest isolated peaks are in this place (Jilani *et al.*, 2007).

According to the IPCC, the most unpredictable risk for mountain communities around the world, related to climate change are floods, avalanches, forest fires and landslides. These extremes are becoming more common in mountainous areas and threatened livelihood by enhanced water losses due to change in precipitation and evaporation patterns (IPCC, 2001). Many mountain people groups depend upon agribusiness for their employments, but climate change seems to have an unfavourable effect on cultivating. Water systems will be influenced, to begin with by floods and after that by drought seasons, making survival harder for subsistence agriculturists as well as those who develop cash crops both in these mountain areas as well as within the lower catchments (Hussain *et al*,2005)

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Climate change has many negative impacts like on agriculture, health, water resources etc. (IPCC, 2007; Amorim *et al.,* 2014; Devkota *et al.,* 2014). There's presently considerable proof that permafrost in most of the world is dissolving owing to increases in temperatures in the mountainous regions, and if case present patterns proceed, numerous of the world's mountain ice sheets will have vanished completely by the conclusion of this century From 1912, the famed snow-capped summit of Mount Kilimanjaro in Tanzania has lost almost 82 percent of its ice, with a third of that loss occurring in the last two decades (Global Mountain Summit, 2002). For instance, the largest remaining ice masses in Montana's Ice Sheet National Park are currently about one-third as large as they were in 1850, and some estimates indicate that all existing ice masses within the park may completely disappear within the next 30 years (US Natural Organization, 2000). Ice sheets within the European Alps and the Caucasus Mountains have contracted to half of their estimate; whereas in Africa as where 8 percent of Mount Kenya is biggest, icy mass remains. Analysts have recorded fast icy mountain mass withdrawal in Greenland, Ecuador, Peru, Venezuela, Modern Guinea, and East Africa, among other places (Mountain Association, 2004).

Rees and Collins (2004) mentioned it in research, that ice sheets within the Himalayas are subsiding speedier worldwide and the probability of vanishing by 2035 is exceptionally high at its present rate. Since the western Himalayas contribute around 60 to 70 percent of snowfall to major river flow, compared to only 10 percent on the eastern side, this effect will be observed more there. (IPCC 2001).

It is mentioned in research that temperature is increasing in winters and spring while there is decrease in summer and autumn temperature (Batool *et al.*2016). In a relation to this, increase in temperature and pollution, glaciers are shrinking at a higher rate. Which ultimately leads to monsoon floods in water channels (Hewitt, 2005; Batool *et al.* 2016).

According to research, Pakistan has 5% forestland cover, which is below the minimum requirement, and it is continuing to decline more in northern areas due to over reliance on forest and other several reasons (Sheikh and Aleem, 1975; Government of Pakistan (GoP), 1991; Food and Agriculture Organization, 1998). Besides socio-economic condition of people, climate change has hastened deforestation. The research revealed that forest cover is declining vigorously in villages as compared to pastures in the district of Skardu, Gilgit Baltistan (Batool *et al.*2016). Moreover, fluctuation in the climate will alter or disturb the functioning ecosystem services. Furthermore, changes in agricultural patterns, season variation, fruit sowing, and harvesting periods have a prolonged impact on the environment. Diseases in plants are increasing and indigenous bird's population are decreasing. In contrast to it there is an increase in exotic bird species in northern parts of Pakistan (Batool, *et al.*2016). Food insecurity is the worst impact of climate change on the mountain community of Pakistan because of their biophysical and socioeconomic factors (Rasul &Hussain, 2015).

1.2. Equilibrium Line Altitude:

The height at which yearly accumulation (net gain) and ablation (net loss) are balanced is known as the equilibrium line altitude (ELA). This definition must be further clarified. The ELA is the average altitude of the equilibrium line, which varies in elevation across the glacier due to local differences in accumulation and ablation. Few, if any, glaciers have zero annual mass balance across their entire breadth. Second, the glacier may be gaining or losing mass annually; the ELA definition does not state that the glacier is in equilibrium as a whole (Benn & Lehmkuhl, 2000). This would have been the ‘snow line' for 18th-century scientists like P. Bouguer (1698–1758) and H. B. de Saussure (1740–99), who only admitted accumulation in the form of snow. Brückner, von Buch, Esmark, Hugi, von Humboldt, Kurowski, Partsch, Payer, Penck, Ratzel, Richter, and von Sonklar examined the snow line in the nineteenth century and discovered that it was lower on a glacier than in its physical vicinity. The term 'firn line' was used to describe the new notion. Before the era of remote sensing, examining snow/firn lines directly on glaciers was very challenging because of the enormous variations in their temporal and spatial distribution but I. Venetz (1788–1859) successfully underlined the snow lines for the swiss alps in 1815-17. (Berchtold and Bumann, 1990). Ahlmann (1923) and SchyttSchytt (1949) acknowledged the significance of meltwater refreezing for mass balance and made it plain that the firn line does not separate the ablation area from the accumulation area, although Baird (1952) is thought to be the first to use the phrase "equilibrium line. The equilibrium line is typically lower than the annual snow/firn line, and the ‘the superimposed ice zone' that exists between the two is the lowest point in the accumulation region where yearly accumulation is in the form of ice via refrozen meltwater instead of snow.(Braithwaite, 2008).

It is stated that ELAs are significant climate indicators because they represent the temperature and precipitation at that particular spot on the glacier. (Oien *et al.,* 2021). The Karakoram's craggy glacier-covered terrains and harsh weather circumstances result in a scarcity of field observations. However, satellite imageries and Digital Elevation models (DEM) (e.g., Glaciers Inventories or derive ELAs) and GIS and Remote based calculations have significantly filled up the gap of knowledge.(Baig & Muneeb, 2021). The ELA is critical to understanding current and historical climates, and variations in ELA elevation can also be used to find out climate change. It's worth noting that paleo-glacier reconstructions assess the ELA under the assumption that the glacier is in balance with the climate. For the glaciers, this is comparable to a zero net balance ELA, but the ELA might be very varied annually. Winter precipitation, which corresponds to accumulation (although this is also influenced by windblown snow accumulation and avalanching), and summer air temperature, which corresponds to ablation are the main ways in which the ELA is linked to the climate (some factors such as shortwave and longwave radiation, heat changes and snowpack warming from refreezing can show a substantial role). However, changes in one or both climatic variables are frequently related to variations in the ELA on a first order basis. In the absence of such data, the ELA is used to analyse the climate during past glaciations as well as the mass balance of existing glaciers. (Braithwaite, 2008; Hughes, 2009; Pellitero *et al.,* 2015)

1.3. Problem Statement:

The Climate is Changing drastically and vigorously, and it is the world's top agenda. According to IPCC the climate change is occurring and hastening. Glaciers in different part of the world and particularly north of Pakistan are melting at a greater rate and posing threats to mountainous communities. There are many kinds of glaciers in the Karakoram region of Pakistan. Owing to the rough terrain covered in glaciers and the paucity of climate data above 5000 masl, field measurements for the estimation of the ELA of most Karakoram glaciers are not available. However, we use GIS and remote sensing techniques to fill the gap of knowledge. We evaluated the ELA and reconstructed the glacier-climate in the Hunza River Basin using the accumulation area ratio (AAR) and accumulation area balance ratio (AABR) approaches. This research is conducted for the first time on these chosen glaciers to know the Area above and below the ELA. Furthermore, this pilot study also serves as a baseline for the monitoring of glaciers mass and informs us about the relation between climate and glaciers (Changes in climatic variables are frequently related to variations in the ELA line).

1.4. Objectives of the Study

The study attempts to present the ELAs of ten (10) glaciers in the Hunza River Basin (HRB) through satellite data and analyse the mass Balance changes across the Basin. The main goals of this study are:

1. To estimate the glacier equilibrium line altitude (ELAs) in the Hunza River Basin
2. To calculate Mass balance and Area Changes above and below ELA of the glaciers.

1.5. Study Area

The present study was carried out in Hunza River Basin with a total area of 13,733km^2. Hunza River Basin is located at 35°36 N and 74°23 E and is a high-altitude mountainous area with a mean elevation of 4650 masl. Glaciers cover about 25% of the basin area (Bloch *et al.,* 2017). The snow-covered region fluctuates from almost 80% in the winter season and 30% during the summer period (Tahir *et al*., 2011). The climate is arid to semiarid. Critical topographies of the Hunza River Basin are displayed in Table 1.1 and figure 1.1. The Basin has two distinctive precipitation patterns, i.e., one in summertime and the other in the winter season. Besides the effect of the global atmospheric circulation system, the mountainous region is also influenced on a local scale by slope, elevation, aspect (Awan, 2002). The Westerlies and the Indian summer monsoon, which bring precipitation in the form of snow that melts in the summer and produces heavy discharges, have a significant impact on the Hunza basin. (Owen & Elias, 2007).

Table 1: Essential features of the Hunza Basin

S.no	Physical characteristics	Descriptions
1.	Catchment area	13,733km^2
2.	Glacier	2754km^2
3.	Clean glacier	2344km^2
4.	Debris-covered glacier	410km^2
5.	Elevation range	1460-7764 m
6.	Latitude	35°54′ to 37°05
7.	Longitude	74°02′ to 75°48
8.	Catchment outlet	Danyore Bridge

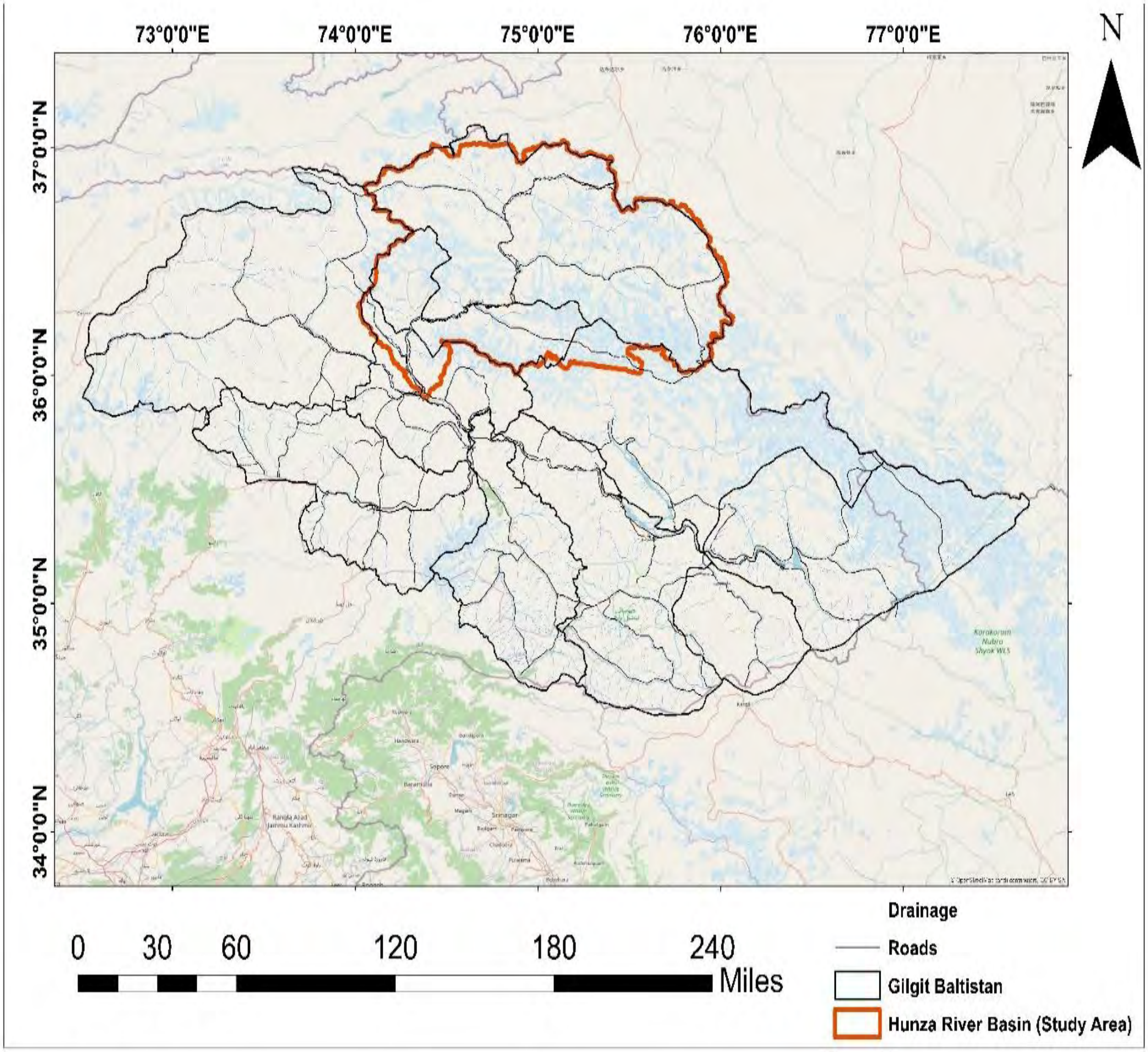


Fig 1: Map of the Study Area

Chapter 2

Methodology

2.1. Glacier Data:

Datasets including glacier outlines are downloaded using a revised version of the Randolph glacier inventory version 6(http://www.glims.org/RGI/randolph60.html). Furthermore, the study employed the DEM retrieved from SRTM with a resolution of 30 m along with the glacier dataset acquired from the Randolph Glacier Inventory (RGI-Version-6) from Glacier Land Surface and Ice Measurements from Space (https://earthexplorer.usgs.gov/). For ELA calculations, the SRTM DEM's Geo TIFF format was employed. It was referred to the WGS 84 geoid and 1 arc of a second 30 m grid of altitude which is more accurate to derive topographic data about glaciers, including their aspect, elevation, and slope. However, the SRTM GDEM digital elevation model employed for this investigation was reasonably accurate and of high quality throughout the Hunza River Basin (HRB).

2.2. Calculating AAR and AABR:

A toolbox formulated by Pike and Wilson given by the the ARCGIS software sponsored by Esri is employed to Calculate Hypsometric Integral (HI) which means the space (Area) underneath the standardised curvature for the Hunza basin. The aggregate distribution glacier altitudes in the Hunza basin or the resulting hypsometric function is utilised to estimate the equilibrium line. For a hypsometric curve (HC) we formulate bins of specified altitude considering their pixels for each glacier in Excel. Then normalised area and elevation are calculated and plotted the graph. The proportion of aggregate normalised elevation to collective normalised area beyond the elevation is represented by hypsometric curvatures created from lowest to the highest altitude. In glacier hypsometry, an above average curvature or/and more convex-downward curvature denotes modest altitudinal changes.

2.3. An Estimation of ELA (AAR and AABR)

If glaciers are in a stable state, the AAR method presumes that the ratio of the accumulation area to the ablation area is constant**.** Moreover, AABR underlines three conditions (a)The accumulation and ablation gradients are roughly linear, (b) the net ratio of ablation to accumulation is known and constant throughout time (c) A change in climate (mass balance) is reflected in a change in the height of the terminal because the topography is considered to confine the glacier. Piedmont glaciers that reach valley plains are an exception to this rule.(Pellitero *et al.,* 2015). A tool developed by (Pellitero *et al.*, 2015) is used in which the iterative process that satisfies the mass balance of the glacier equation for a specific elevation range of the distinctive glacier digital elevation model is used to find and compute the ELA of ten glaciers in Hunza River Basin (HRB) for a given AAR(0.6 for Cirque and valley Glaciers) Bakke and Nesje (2011) and AABR value (2.24 for high altitude glaciers) Rea (2009). The tools use the González Trueba and Serrano (2004) method for the AAR computation and the Osmaston (2005) procedure for the AABR. These glaciers are positioned transversely in several marginally varied climate zones. we initially computed zero net-balance ELAs for each glacier. Assuming these ten glaciers in HRB are in equilibrium with climatic circumstances.

2.4. ELA Toolbox:

In this research we used Digital Elevation Model (DEM) of the glacier surface is needed as the primary input for the ELA calculation toolbox, and a folder is needed to save the results. Any raster file that ArcGIS 10.8 supports can be used with the DEM. Four Python-coded tools and one model are included in the toolbox to create the DEM from contour lines. The tools also need two more parameters. The first is the contour interval used to calculate the glacier area. Although 50 m is the default, the user has the option to adjust it. Keep in mind that it also depends on the glacier's size and the DEM's vertical resolution**.** Secondly**,** the ratio between the AAR and AABR procedures. In nutshell, to calculate ELA we need three things; The contour that corresponds to the ELA is prepared as a shapefile. A polyline shapefile or feature class with a subject named "CONTOUR" and data in it must be the first input. This field must contain the elevation of each contour (metre above sea level). the glacier outline, which can either be a polyline or a polygon, is the second input. The final input is the output DEM's name and location. The script initially starts the tool to determine the area over (for AAR) and under (for AA and AABR) the "trial" altitudes as many times as necessary given the selected contour interval and the glacier altitudinal range (which is determined automatically). Results are saved as a text file with the extension.txt that is called after the DEM and kept in the selected folder. The script then calculates the ELA after reading the pertinent data from the text file. The two parameters are considered to estimate are the height and area of that specified value.

This toolbox is designed to function with ArcGIS 10.8 and later editions. Additionally, it needs a 3D Analyst tool and Spatial Analyst tool. However, it can be took through Git-Hub repository at https://github.com/cageo/Pelli tero-2015 from the Younger dryas group website in the University of Aberdeen http://www.abdn.ac.uk/geosciences/depart ments/geography-environment/outcomes-442.php.

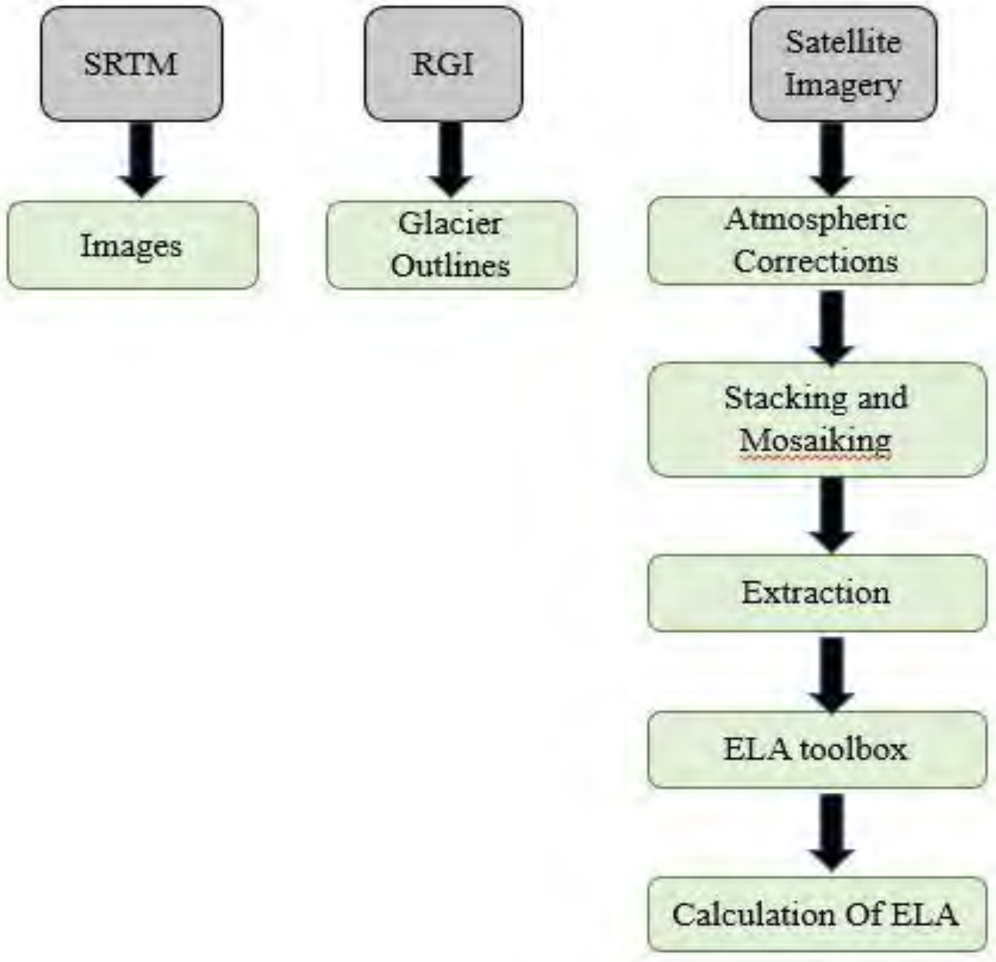


Figure 2: Flowchart illustrating methodology for the calculation of ELA

Chapter 3

Results and Discussion

3.1.Vertical and horizontal climate:

3.1.1. Glaciated Region:

The Hunza River Basin's glaciated area is depicted on a map in Figure 3.1 (a), along with the glacier outlines. Figure 3.1 (b) shows the locations of two ELAs for the Hunza basin in 2015 and the Karakoram in 1989 over a histogram of the frequency distribution of elevations. Respectively, the bottom and top of Figure shows elevations and the associated climatic settings of glaciated terrain in Karakoram, as determined by Mukhopadhyay *et al*. (2015) and Wake (1989). According to Wake (1989), the glaciated landscape is divided into five zones: ablation zones I (2561–3945 m), Ablation zone II (3945–4619 m), avalanche nourishment of ice/zone of snowfall/accumulation (4620–5130 m), and direct accumulation (5131–5752 m) Accumulation wind region (5752 – 7886 m). Between the elevations of 3500 and 5000 feet, high altitude melt is documented in the zone of ablation, melt, and freezing. Majority of the glaciated area (28.6%) is in the central band, between 4500 and 5000 m (direct accumulation), irrespective of wide variety of glaciated elevations in the Hunza River Basin. The yearly average temperature and precipitation at this altitude are correspondingly between -5 and - 10°C and 1700 and 1900 mm respectively. The shortest portion of the glaciated terrain (3.27 percent) is at the least altitudinal range (between 2561 and 3672.5 m), relating to carbon contain -covered ice of the vertical regime and net retreat and the middle velocity zone of the horizontal regime, where the average yearly temperature is above +10°C, while 6.68% of the glaciated area is located at the maximum elevation of the largest altitudinal range (between 6457.5-7889 m), pertaining to net accretion in glaciated area.

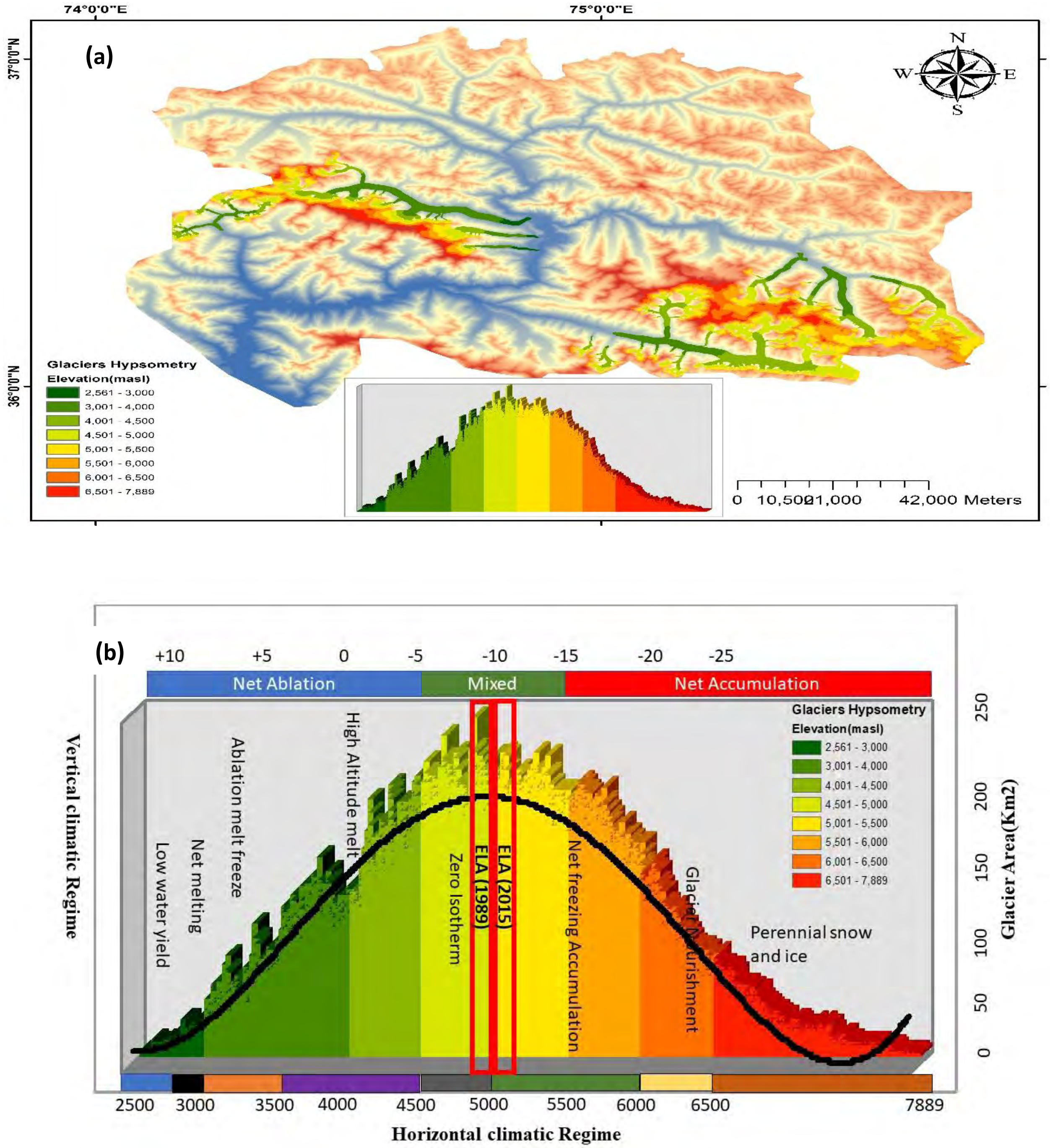
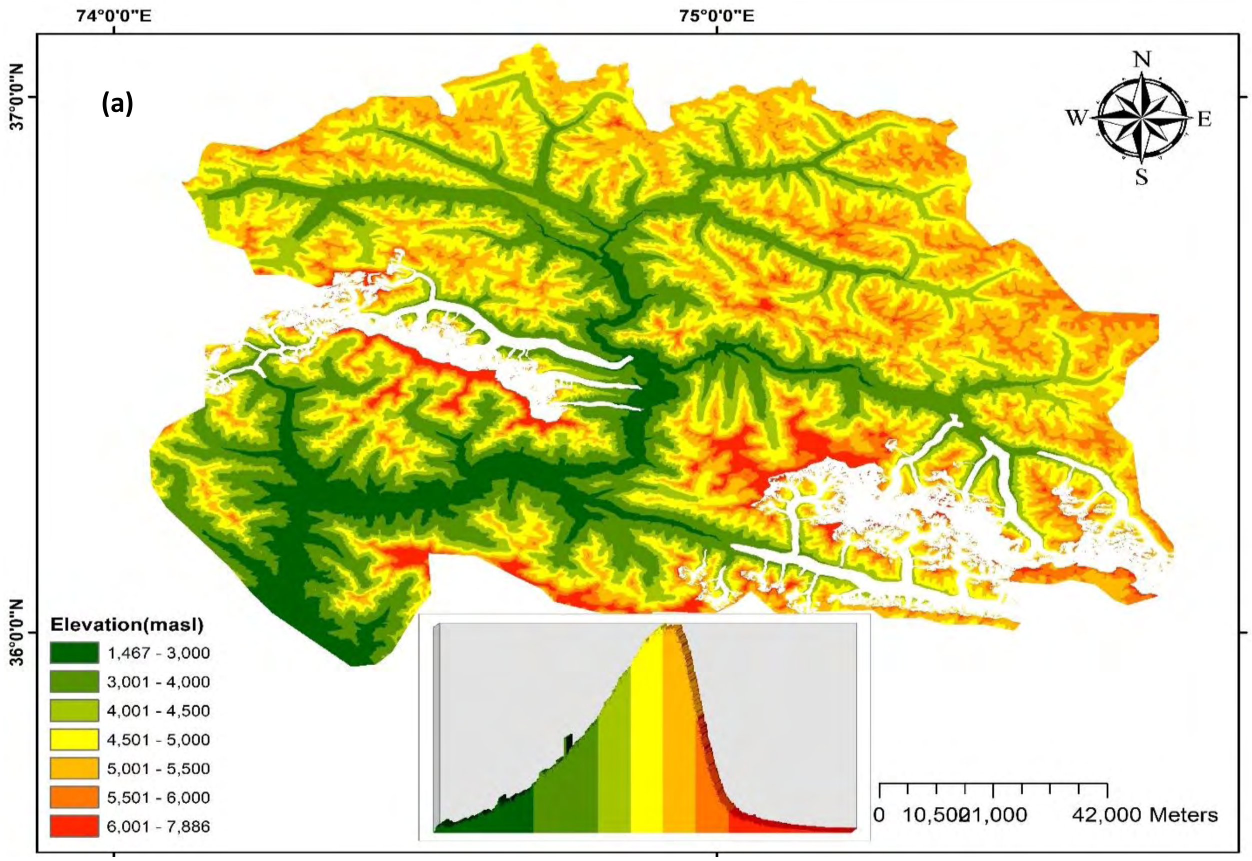


Fig 3: **(a)** the mean annual temperature (°C) values, a histogram (glaciated terrain corresponding to parallel frequency of elevations**)**, **(b).** Zones and climate data are shown on the top of the map (Wake,1989), while zones and climate data are shown at the top of the map based on a more generalised model built by using climatic data (2007-2010) by Mukhopadhyay and Khan (2015).

3.1.2. Non- Glaciated Landscape:

The greatest landscape area (43.40 %) is located between 4800 and 5200 metres, whereas the next-largest landscape area (23%) is located amid 3000 and 4000 metres. According to Wake (1989) model, the average annual temperature and precipitation stays in the middle of -1°C and -10°C and 1400 and 1800 mm, at elevations of 3000 to 4000m respectively, and between -9°C and -17°C and 1700 and 2000mm at the elevations of 5000 to 6000m. Moreover, -20°C is at 6000 - 6400 and -25 is at 6400-7886. The lowest non-glaciated landscape (9.4%) is located at the last end of the elevation range with the smallest average yearly temperature (above +6°C) and insignificant Average precipitation, while 0.09 percent is located at the last end of the elevation series with the largest mean annual temperature (above 7000m), which is extremely cold and freezing (-22°C) as shown in figure 3.2.



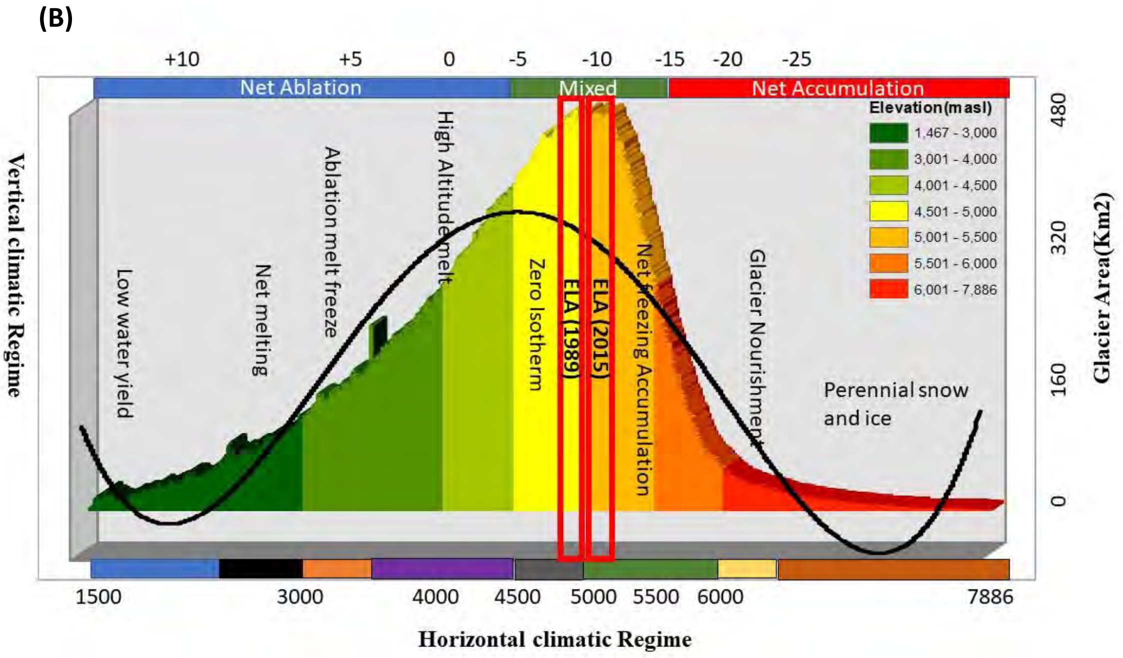
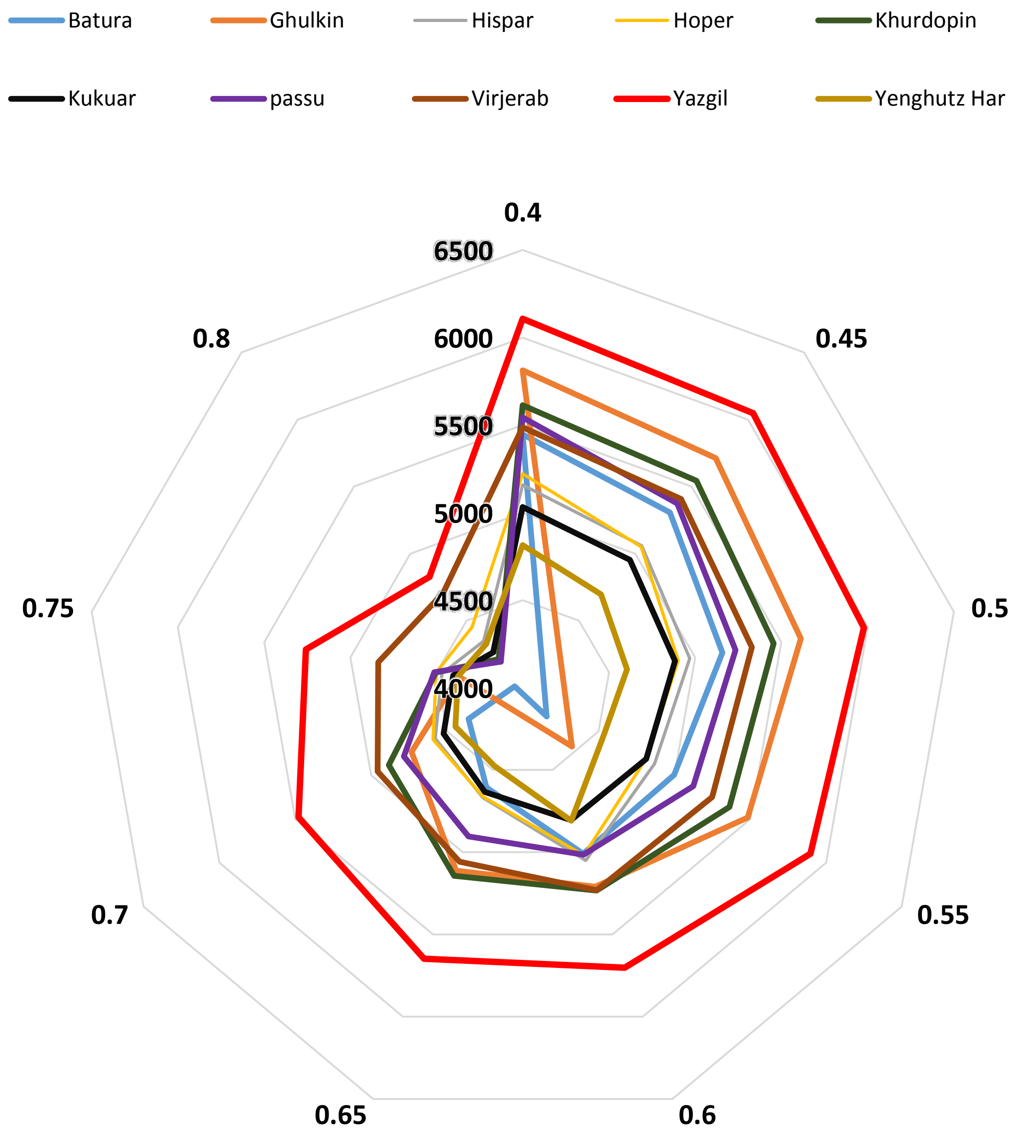


Fig 4: (a) the mean annual temperature (°C) values, a histogram (non- glaciated terrain corresponding to parallel frequency of elevations), **(b).** Zones and climate data are shown on the top of the map (Wake,1989), while zones and climate data are shown at the top of the map based on a more generalised model built by using climatic data (2007-2010) by Mukhopadhyay and Khan (2015).

3.2. Equilibrium Line Altitude sensitivity to AAR and AABR:

Variation in ELA to future AAR and AABR ratios indicate that how much geometry(area) is under the ablation and accumulation zone. For example, for Batura glacier the ELA shows decreasing trend of from 5157 to 4997 (masl) at a ratio of (0.5-0.6) which means it loses around 6% areas. A significant loss of 402m-ELA of same glacier is seen at elevation of 5009-4607 at the ratio of 0.6 to 0.65 which indicates the loss of 36% of area. For Ghulkin glacier significant loss of 810m ELA is scene at the elevation of 4373-3563(masl) at 0.75 to 0.8 which shows 46% loss of area in this specified range. Hisper glacier indicates the decreasing trend of 381m ELA shows loss of 32 % at the elevation of 5049-4668 (masl) at a ratio (0.6- 0.65). Likewise, Hopper glacier shows same trend at the same ratio (0.6 to 0.65) at the elevation of 5028-4662 (masl) and it shows 27% loss of geometry. Khurdopin also indicates decreasing trend of 380m ELA at elevation 4884-4504 (masl). The changes are ELA is shown in Table 3.1 for AAR (0.4-0.8) and table 3.2 for AABR (0.9-4.4) for all glaciers. Variation in geometries is shown in figure 3.3(a) for AAR and (b) for AABR. All these glaciers are forecast to incur very varying geometry (area) losses, with bigger glaciers (Hisper, Batura and Kukuar) predicted to suffer greatest substantial losses at elevations (4000–5400 m) in glacier ice zone. At the smallest elevations for AAR, the lowest glacier area reductions are documented. Our findings indicate that a 100m ELA decrease (Fig. 4a) will result in an increase of 10% in the number of HRB glaciers, a 15% increase in glacier area, and a 12% increase in glacier volume. Moreover, 200 m of more extreme ELA reduction results in increases of 40%, 30%, and 22%, respectively.

(a)


Batura
Ghulkin
Hispar
Hoper
Khurdopin
Kukuar
passu
Virjerab
Yazgil
Yenghutz Har
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
6500
6000
5500
5000
4500
4000

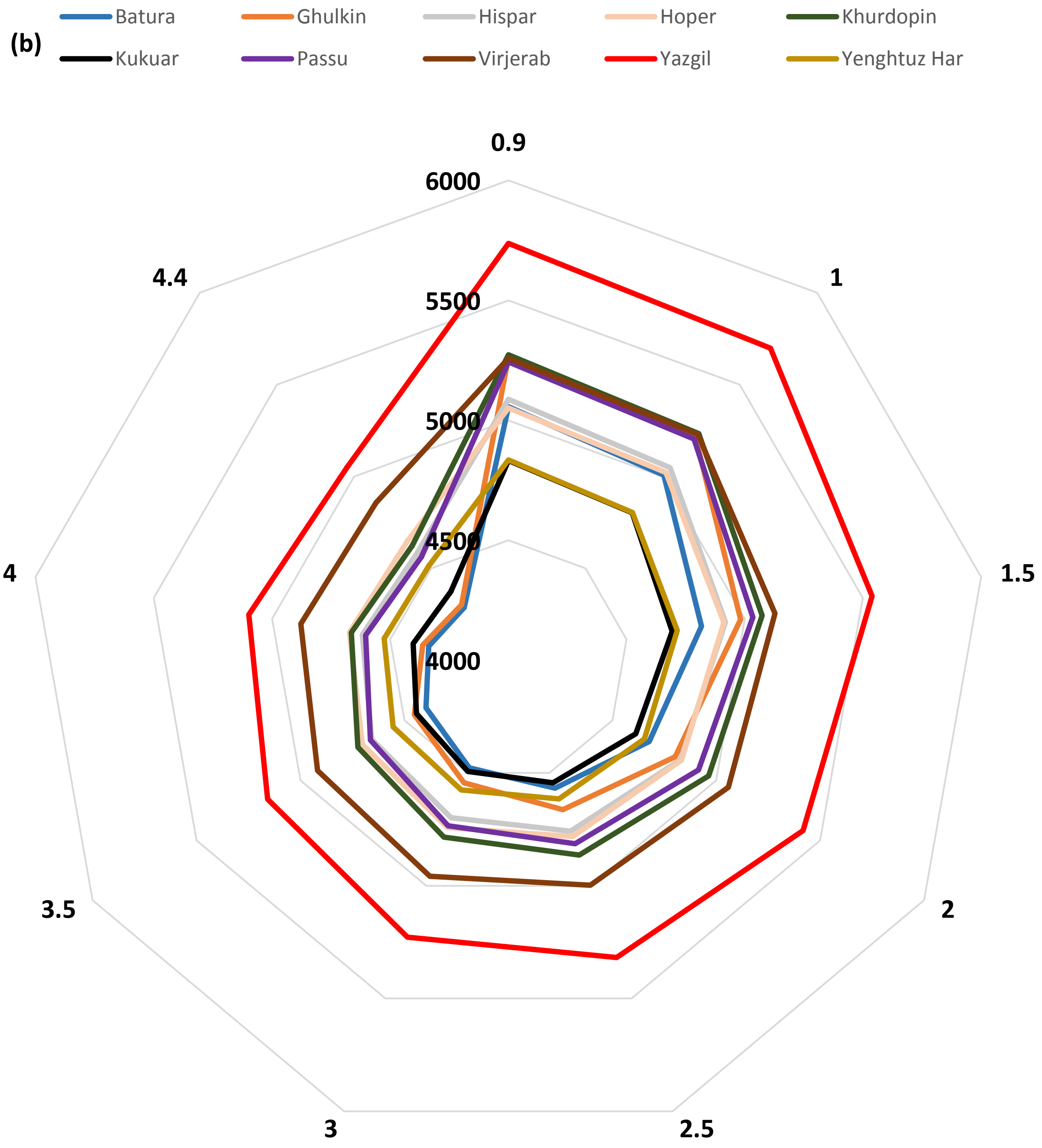


Fig 5. Glacier geometries are modified to account for proposed changes in ELA for **(a)** steady value of AAR (0.4- 0.8) by a 0.05 interval and **(b)** AABR (between 0.9-4.4) by a 0.5 interval**.**

Table 2: Equilibrium Line altitudes of ten glaciers along with the AAR ratio (0.4-0.8) with an interval of 0.05

	Ratio	Batura GL (masl)	Ghulkin GL (masl)	Hispar GL (masl)	Hoper GL (masl)	Khurdopin GL (masl)	Kukuar GL (masl)	Passu GL (masl)	Virjerab GL (masl)	Yazgil GL (masl)	Yenghutz Har GL (masl)
AAR$_1$	0.4	5447	5813	5158	5222	5614	5033	5544	5488	6108	4815
AAR$_2$	0.45	5307	5713	5058	5052	5544	4953	5374	5408	6048	4695
AAR$_3$	0.5	5157	5613	4968	4902	5454	4883	5234	5328	5978	4605
AAR$_4$	0.55	4997	5483	4868	4812	5364	4813	5124	5248	5898	4535
AAR$_5$	0.6	5009	5210	5049	5018	5233	4804	5014	5231	5701	4808
AAR$_6$	0.65	4607	5113	4668	4662	5144	4633	4904	5058	5648	4475
AAR$_7$	0.7	4357	4733	4578	4592	4884	4523	4784	4958	5478	4445
AAR$_8$	0.75	4047	4373	4468	4502	4504	4403	4514	4838	5258	4375
AAR$_9$	0.8	3787	3563	4348	4452	4214	4263	4194	4708	4828	4325

Table 3: Equilibrium Line altitudes of ten glaciers along with the AABR ratio (0.9-4.4) with an interval of 0.01

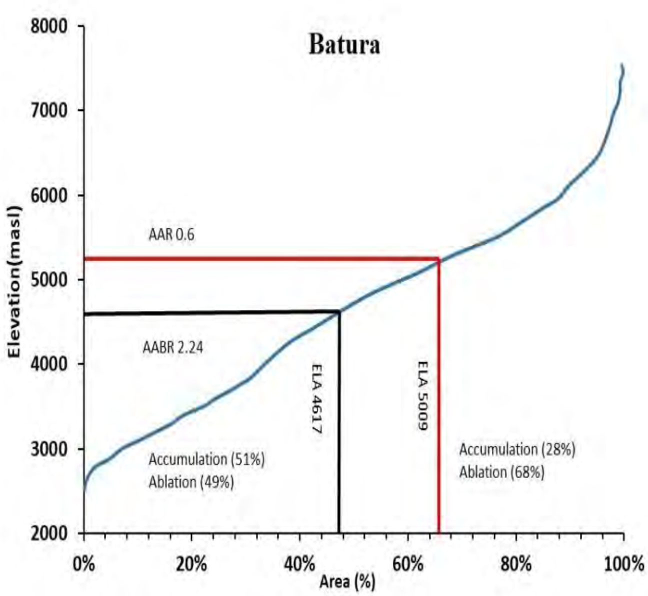
AABR Ratio	Batura GL (masl)	Ghulkin GL (masl)	Hispar GL (masl)	Hoper GL (masl)	Khurdopin GL (masl)	Kukuar GL (masl)	Passu GL (masl)	Virjerab GL (masl)	Yazgil GL (masl)	Yenghutz Har GL (masl)
0.9	5057	5263	5088	5052	5274	4833	5244	5258	5738	4835
1.0	5007	5213	5048	5022	5234	4803	5204	5228	5698	4805
1.1	4967	5153	5018	4992	5194	4783	5164	5208	5668	4785
1.2	4927	5113	4988	4972	5164	4753	5124	5188	5628	4765
1.3	4887	5063	4968	4952	5134	4733	5094	5168	5598	4745
1.4	4847	5023	4938	4932	5104	4713	5064	5148	5568	4735
1.5	4817	4983	4918	4912	5074	4693	5034	5128	5538	4715
1.6	4787	4943	4898	4892	5054	4673	5004	5118	5518	4705

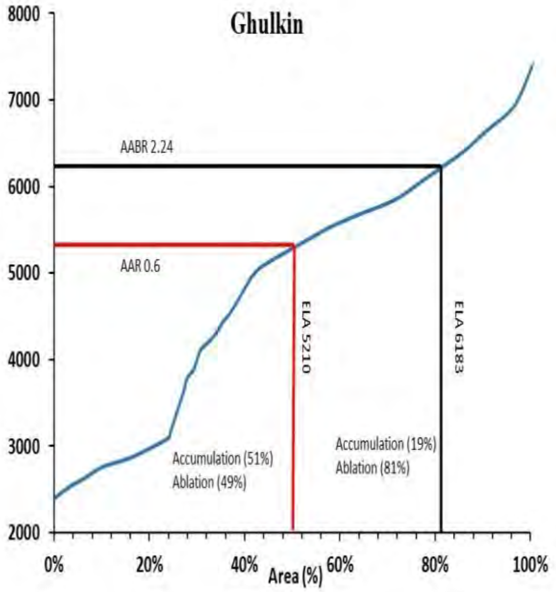
1.7	4757	4903	4878	4882	5024	4653	4984	5098	5488	4685
1.8	4727	4873	4858	4862	5004	4643	4954	5088	5468	4675
1.9	4697	4833	4838	4852	4984	4623	4934	5068	5438	4665
2.0	4677	4803	4828	4832	4964	4613	4914	5058	5418	4655
2.1	4647	4773	4808	4822	4944	4593	4894	5048	5398	4645
2.24	4617	6183	6648	5962	6584	5893	6664	5998	6878	5915
2.3	4607	4713	4778	4802	4904	4573	4854	5018	5358	4625
2.2	4627	4743	4798	4812	4924	4583	4874	5038	5378	4635
2.5	4567	4663	4758	4782	4864	4543	4814	4998	5318	4615
2.6	4547	4643	4748	4772	4854	4533	4794	4988	5298	4605
2.7	4527	4613	4738	4762	4834	4523	4784	4978	5278	4595
2.8	4507	4593	4718	4752	4814	4513	4764	4968	5268	4585
2.9	4487	4573	4708	4742	4804	4503	4744	4958	5248	4585
3.0	4477	4543	4698	4742	4784	4493	4734	4958	5228	4575
3.1	4457	4523	4688	4732	4774	4483	4714	4948	5218	4575
3.2	4437	4503	4688	4722	4764	4473	4704	4938	5198	4565
3.3	4427	4483	4678	4712	4744	4463	4694	4928	5188	4565
3.4	4417	4463	4668	4712	4734	4453	4674	4918	5178	4555
3.5	4397	4453	4658	4702	4724	4443	4664	4918	5158	4555
3.6	4387	4433	4648	4692	4714	4433	4654	4908	5148	4545
3.7	4367	4413	4638	4692	4704	4433	4634	4898	5128	4545
3.8	4357	4393	4628	4682	4694	4423	4624	4888	5118	4535
3.9	4347	4383	4628	4682	4674	4413	4614	4888	5108	4535
4.0	4337	4363	4618	4672	4664	4403	4604	4878	5098	4525
4.1	4327	4343	4608	4672	4654	4403	4594	4868	5088	4525
4.2	4307	4333	4608	4662	4644	4393	4584	4868	5068	4525
4.3	4297	4313	4598	4662	4634	4383	4574	4858	5058	4515
4.4	4287	4303	4588	4652	4624	4373	4564	4858	5048	4515

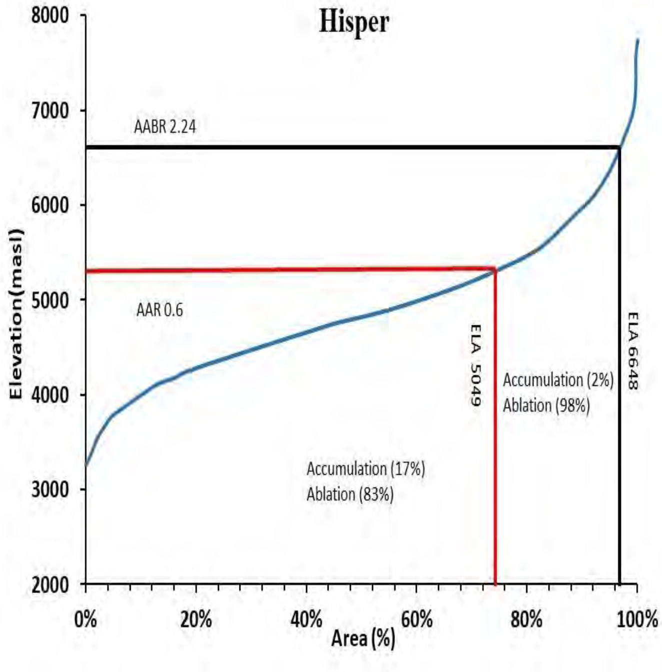
3.3. Calculation the area above (Accumulation) and the below (ablation) the Equilibrium line Altitude:

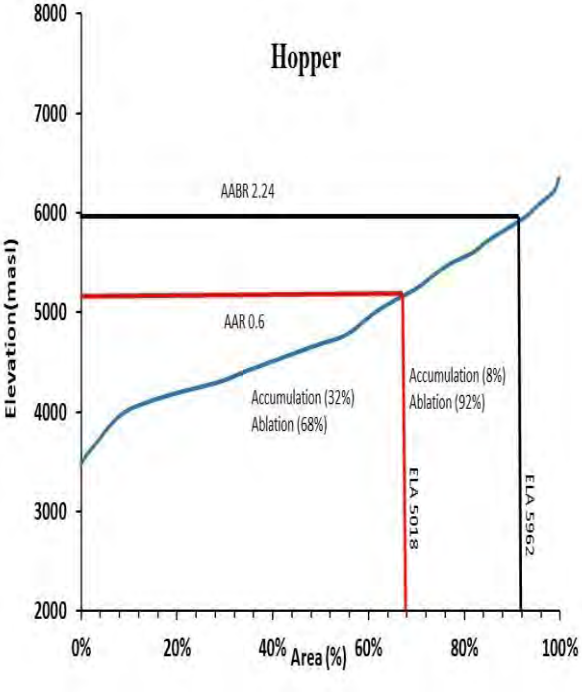
In this research, recommended AAR (0.6) and AABR (2.24) ratios are used for cirque and valley glaciers (Bakke and Nesje, 2011) and for Highland glaciers (Rea, 2009) respectively. As shown in (Fig.3.4)

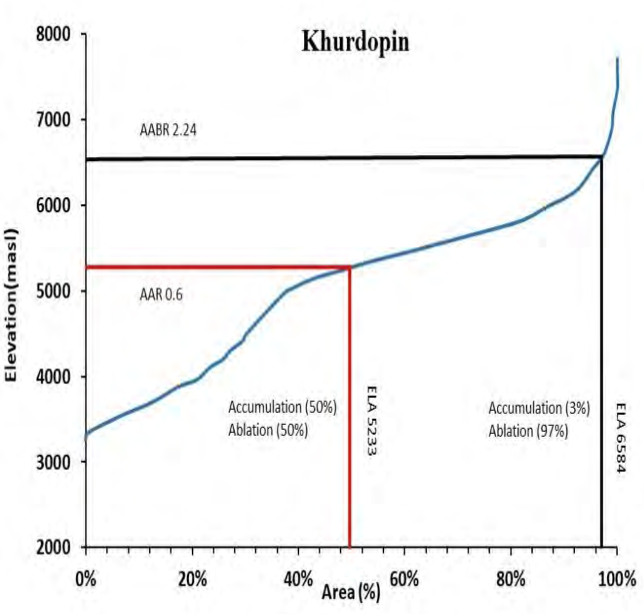
Most of the Batura glacier (76.26%) is located at intermediate altitudes, particularly between 3500 and 6500 metres where the bend on the graph is smoother. The area which is under accumulation (28%) is restricted to the perpendicular (sharper) part of the bend on the curvature (below 5009 m) and 68% area is under the ablation for AAR (0.6) while for AABR the area (below 4617 m) covering 51% is accumulation and 49% area is under the ablation. Moreover, most of the Ghulkin glacier (22.50%) is located at intermediate altitudes, between 4860 and 6310 metres where the bend on the graph is smoother. The area (51%) under accumulation is restricted to the perpendicular (sharper) part of the bend on the curvature (below 5210 m) and 49% area under ablation is observed for accumulation area ratio (0.6) while for AABR (below 6183 m) covering 19% area under accumulation and 81% area under ablation is observed. Similarly, Hisper glacier occupies majority area (10%) at intermediate altitudes, particularly between 4000 and 5000 metres where the bend on the graph is smoother. The area (17%) under accumulation is restricted to the perpendicular (sharper) part of the bend on the curvature (below 5210 m) and 83% area under the ablation for accumulation area ratio (0.6) while for AABR (below 6648 m) covering 2% area under accumulation and 98% area under ablation was observed. Likewise, Hopper glaciers occupies 67.5% area between the 4175-5500m where the bend is steady on the graph. The area under accumulation (32%) is restricted to the perpendicular (sharper) end of the curvature above 5018 m and below 68% area under the ablation for accumulation area ratio (0.6) and according to accumulation area balance ratio (2.24) above 5962 m covering 8% area is under the accumulation and above is the 92% area in in the ablation region. Furthermore, Khurdopin Glacier, occupies 49.7% area between the 5000-6000m where the curvature is smooth. For accumulation area ratio (0.6) the (50%) area is under the accumulation above 5233 m and below there is 50% ablation area and according to accumulation area balance ratio (2.24) above 6584m covering 3% area which is under the accumulation and below 97% area is the ablation part of the glacier. Kukuar glacier occupies 55.4% area between the 4500-5500m. The area (46%) under accumulation is restricted to the (sharper) part of the bend on the curvature above 4804m and below 56% area is under the ablation for accumulation area ratio (0.6) and according to accumulation area balance ratio (2.24) above 5893 m covering 8% area under accumulation and below 92% area is under the ablation region of the glacier. Most of the passu glacier (71.2%) is located at intermediate altitudes, particularly between 3500 and 6000 metres where curvature is smoother. The accumulated region (52%) is restricted to the perpendicular (steeper) region of the hypsometric arch above 5014 m and below 48% ablation region for accumulation area ratio (0.6) in corresponding to below 6664m including 87% accumulated area and 13% retreating area for accumulation area balance ratio (2.24) to the overall glaciated zone. Furthermore, Virjerab Glacier, occupies 70.2% area between the 4300-5700m where the bend on graph is smooth. For accumulation area ratio (0.6) the (47%) area is under the accumulation above the 5231 m and below there is 53% area is under the ablation region and while according to accumulation area balance ratio (2.24) above 5998m covering 3% area is under the accumulation and below 97% area is under the ablation for the observed glacier. Yazgil glacier occupies 46.3% area between the 5500-6400m where the curvature is flat as shown the graph. The area (64%) which is under the accumulation region is restricted to the sharper part of the bend above 5701m and below 36% area is under the ablation for accumulation area ratio (0.6) and according to accumulation area balance ratio (2.24) above 6878 m covering 9% area is under the accumulation and below 91% area is under the ablation to the total glacial area. Moreover, Yenghutzhar Glacier, occupies 35% area between the elevation of 4300-4600. For accumulation area ratio (0.6) the area under accumulation (37%) seems to be restricted to the sharper part of the curvature as shown in graph which is above 4808 m and below there is 63% area under ablation and according to accumulation area balance ratio (2.24) above 5915m covering 8% area under accumulation and below 92% area is under the ablation zone for total glaciated area.

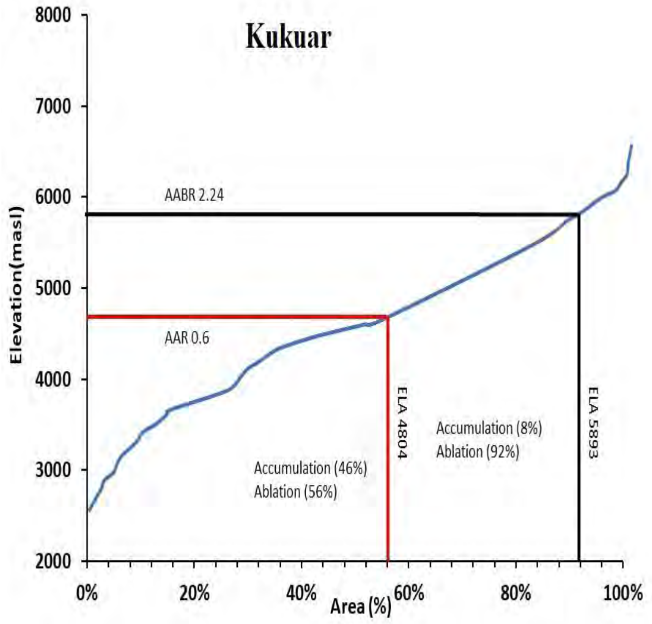

Batura
8000
7000
6000
5000
4000
3000
2000
Elevation(masl)
AAR 0.6
AABR 2.24
ELA 4617
ELA 5009
Accumulation (51%)
Ablation (49%)
Accumulation (28%)
Ablation (68%)
0%
20%
40%
60%
80%
100%
Area (%)

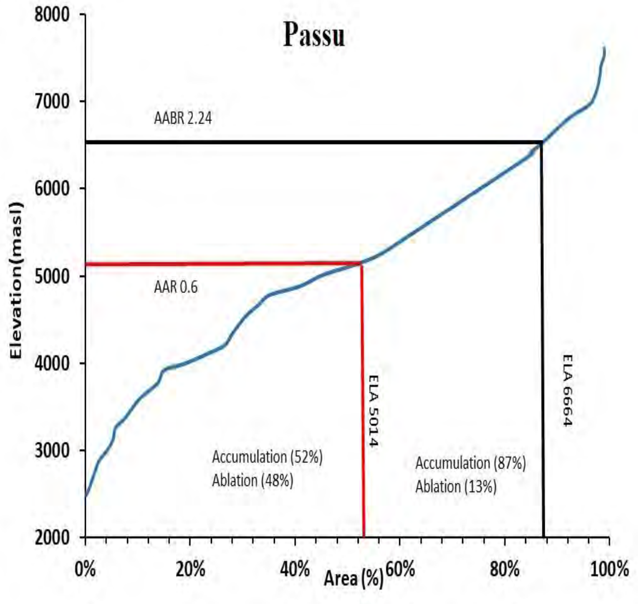

Ghulkin
8000
7000
6000
5000
4000
3000
2000
AABR 2.24
AAR 0.6
ELA 5210
ELA 6183
Accumulation (51%)
Ablation (49%)
Accumulation (19%)
Ablation (81%)
0%
20%
40%
60%
80%
100%
Area (%)

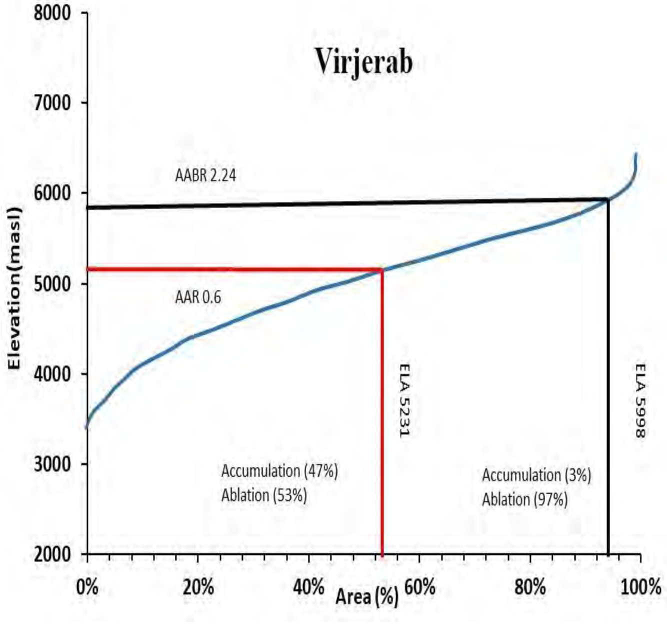

Hisper
8000
7000
6000
5000
4000
3000
2000
Elevation(masl)
AABR 2.24
AAR 0.6
ELA 5049
ELA 6648
Accumulation (2%)
Ablation (98%)
Accumulation (17%)
Ablation (83%)
0%
20%
40%
60%
80%
100%
Area (%)


Hopper
8000
7000
6000
5000
4000
3000
2000
Elevation(masl)
AABR 2.24
AAR 0.6
Accumulation (8%)
Ablation (92%)
Accumulation (32%)
Ablation (68%)
ELA 5018
ELA 5962
0%
20%
40%
60%
80%
100%
Area (%)


Khurdopin
8000
7000
6000
5000
4000
3000
2000
Elevation(masl)
AABR 2.24
AAR 0.6
Accumulation (50%)
Ablation (50%)
ELA 5233
Accumulation (3%)
Ablation (97%)
ELA 6584
0%
20%
40%
Area (%)
60%
80%
100%


Kukuar
8000
7000
6000
5000
4000
3000
2000
Elevation(masl)
AABR 2.24
AAR 0.6
Accumulation (46%)
Ablation (56%)
ELA 4804
Accumulation (8%)
Ablation (92%)
ELA 5893
0%
20%
40%
Area (%)
60%
80%
100%


Passu
8000
7000
6000
5000
4000
3000
2000
Elevation(masl)
AABR 2.24
AAR 0.6
Accumulation (52%)
Ablation (48%)
ELA 5014
Accumulation (87%)
Ablation (13%)
ELA 6664
0%
20%
40%
Area (%)
60%
80%
100%


Virjerab
8000
7000
6000
5000
4000
3000
2000
Elevation(masl)
AABR 2.24
AAR 0.6
Accumulation (47%)
Ablation (53%)
ELA 5231
Accumulation (3%)
Ablation (97%)
ELA 5998
0%
20%
40%
Area (%)
60%
80%
100%

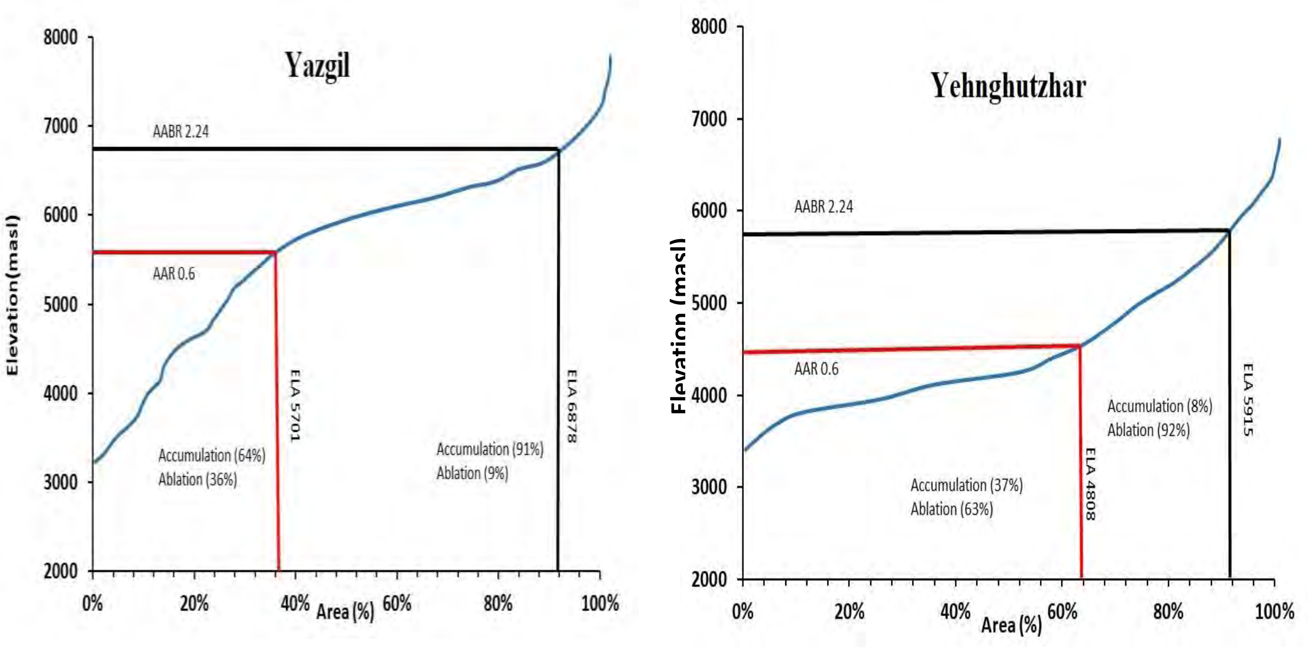


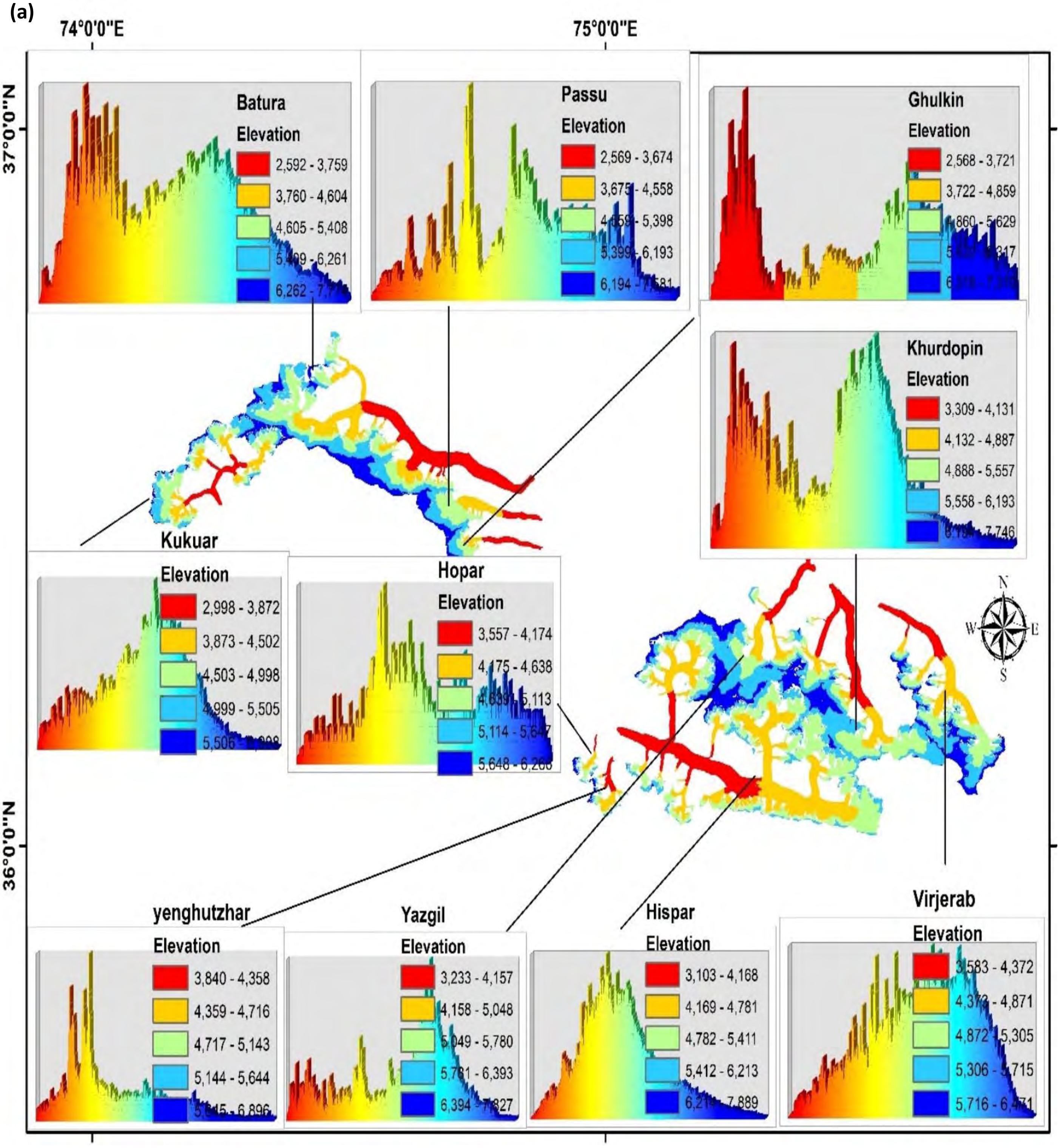
Fig 6: Total percentage area of the surfaces for constant AAR (0.6) and AABR (0.9) values, Plotted against the elevation range (in masl) of 10 glaciers. The total percentage of the glacier surfaces that fall inside the equilibrium line altitude of AAR (0.6) and AABR (2.24) contours shown**.**

3.4.Glaciers Hypsometry:

Most of the glaciers (Hopper, Hisper, Khurdopin, Virjerab, Yazgil, Yehnghutzhar) are found in the north- east of Hunza Basin while other four glaciers (Kukuar, Batura, Passu, Ghulkin) are found in southwest of the basin. Each glacier exhibits some unique characteristics. (1) Batura glacier is the largest (57km) among these above-mentioned glaciers (Anwar et al.,2018) and it occupies an area of 294.1 km2. Most of its glaciated region found on the elevation of 4600-5500 and smallest at 6500- 7774m. (2) Passu Glacier is 38km long (Anwar et al.,2018) which occupies an area of 58.7 km2 and its majority of glaciated region found between 4559-5398m and smallest at the elevation of 7000- 7581m. (3) Ghulkin glacier is 18km long (Ashraf et al., 2014) which occupies 28.8 km2 and its majority of glaciated region found between 5629-6200m and smallest at the elevation of 6900-7310m. (4) Kukuar glacier is 20km long (Williams et al.,1998) which occupies an area of 58.7 Km2 and its majority of glaciated region is seen at 4900-5300m and smallest is at the elevation of 6500-6896m. (5) Hopper is

20 km in length (Gardner et al., 1990) and it occupies 8.34 Km2 of area. Moreover, its majority of glaciated regions found between the elevation of 4350-5000m, and smallest is at the elevation of 5900-6299. (6) Hisper is 50km long (Paul et al., 2017) and it occupies an area of 46.5Km2. Most of its glaciated region found at the elevation of 4500-5400m and its smallest region is between the elevation of 6500-7889m. (7) Khurdopin is 47km long (Iturrizaga. L, 2004) and it occupies an area of 181.5 Km2. Most of its glaciated region found at the elevation of 5300-5800m and its smallest region is at the elevation of 7000-7746m. (8) Virjerab occupies an area of 157.6 Km2. Most of its glaciated region found between 5000-5200m and its smallest region is between the elevation of 6000-6471m. (9) Yazgil is 31km long (Iturrizaga. L, 2004), and it occupies an area of 126.3 Km2. Most of its glaciated region found between 5500-5750m and smallest region is between an elevation of 7200-7827m. (10) Yenghutzhar glacier, occupies an area of 16.9Km2. Most of its glaciated region found at the elevation of 500-5500m and the smallest region is at the elevation of 5645-6896m. As shown figure 3.5 (a) and (b).

(a)


74°0'0"E
75°0'0"E
37°0'0"N
36°0'0"N
Batura
Elevation
2,592 - 3,759
3,760 - 4,604
4,605 - 5,408
5,409 - 6,261
6,262 - 7,7
Passu
Elevation
2,569 - 3,674
3,675 - 4,558
4,559 - 5,398
5,399 - 6,193
6,194 - 7,581
Ghulkin
Elevation
2,568 - 3,721
3,722 - 4,859
4,860 - 5,629
6,317
Khurdopin
Elevation
3,309 - 4,131
4,132 - 4,887
4,888 - 5,557
5,558 - 6,193
7,746
Kukuar
Elevation
2,998 - 3,872
3,873 - 4,502
4,503 - 4,998
4,999 - 5,505
5,506
Hopar
Elevation
3,557 - 4,174
4,175 - 4,638
4,639 - 5,113
5,114 - 5,647
5,648 - 6,266
N
W
E
S
yenghutzhar
Elevation
3,840 - 4,358
4,359 - 4,716
4,717 - 5,143
5,144 - 5,644
5,645 - 6,896
Yazgil
Elevation
3,233 - 4,157
4,158 - 5,048
5,049 - 5,780
5,781 - 6,393
6,394 - 7,827
Hispar
Elevation
3,103 - 4,168
4,169 - 4,781
4,782 - 5,411
5,412 - 6,213
6,214 - 7,889
Virjerab
Elevation
3,583 - 4,372
4,373 - 4,871
4,872 - 5,305
5,306 - 5,715
5,716 - 6,471

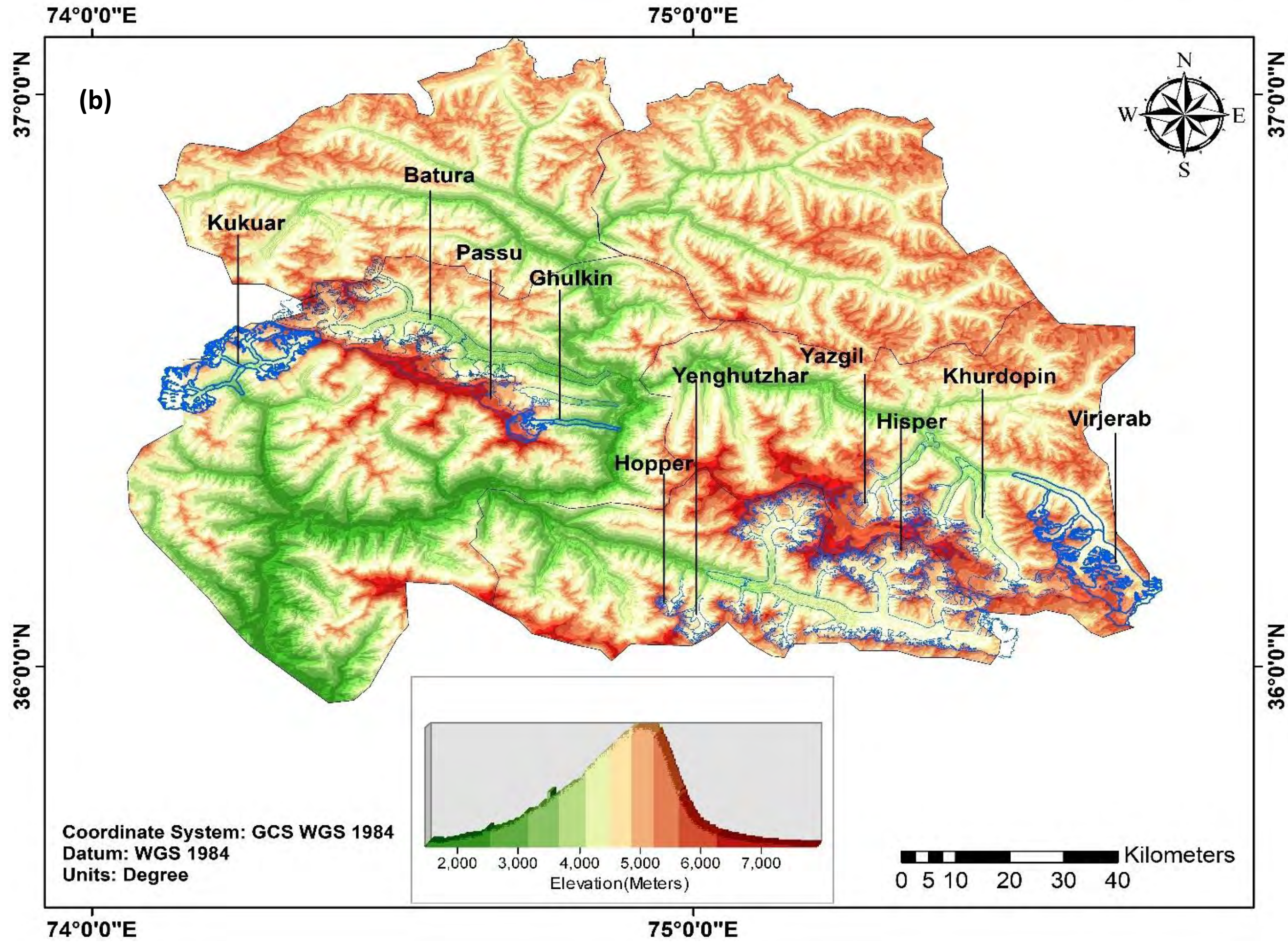
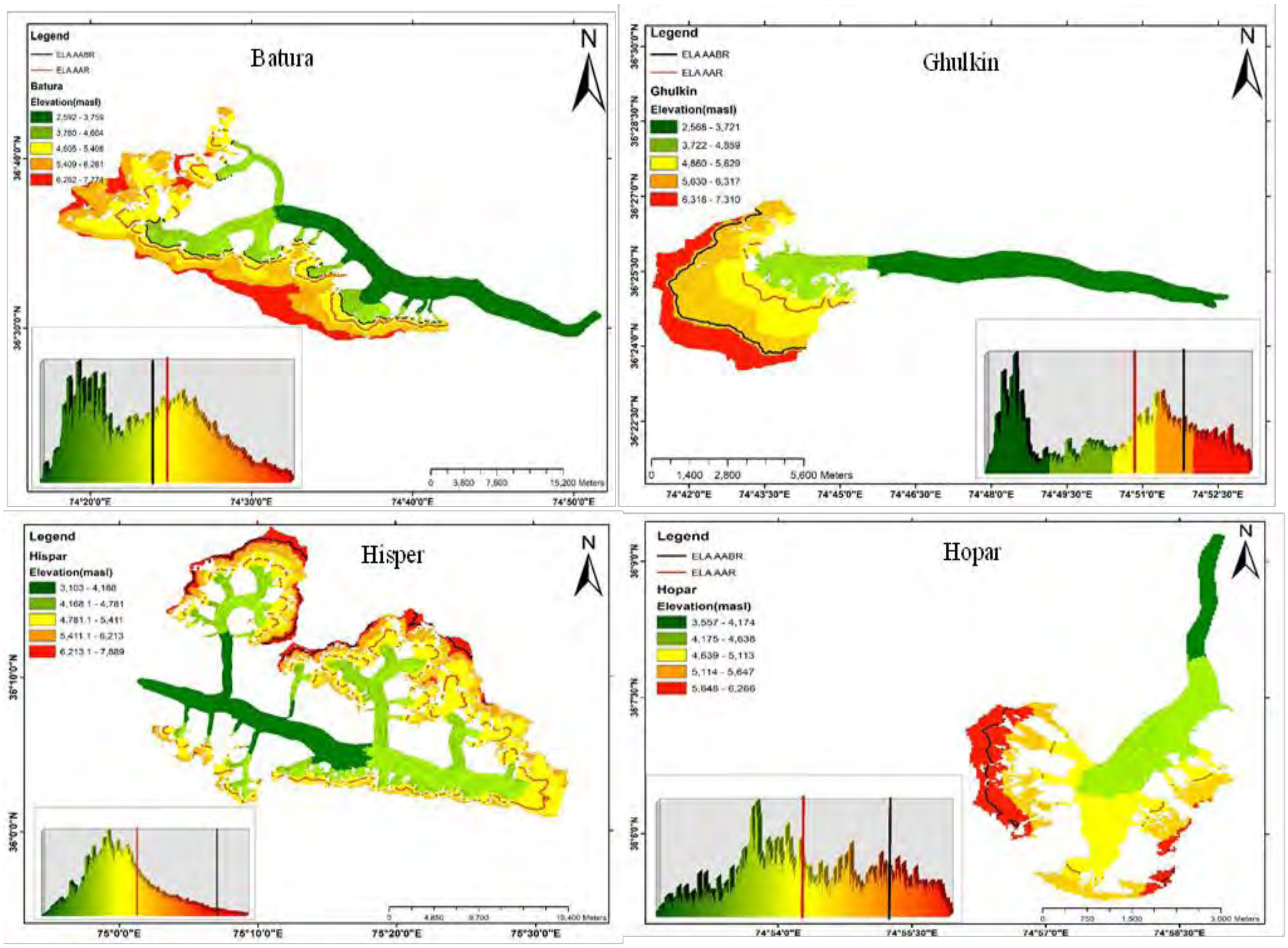
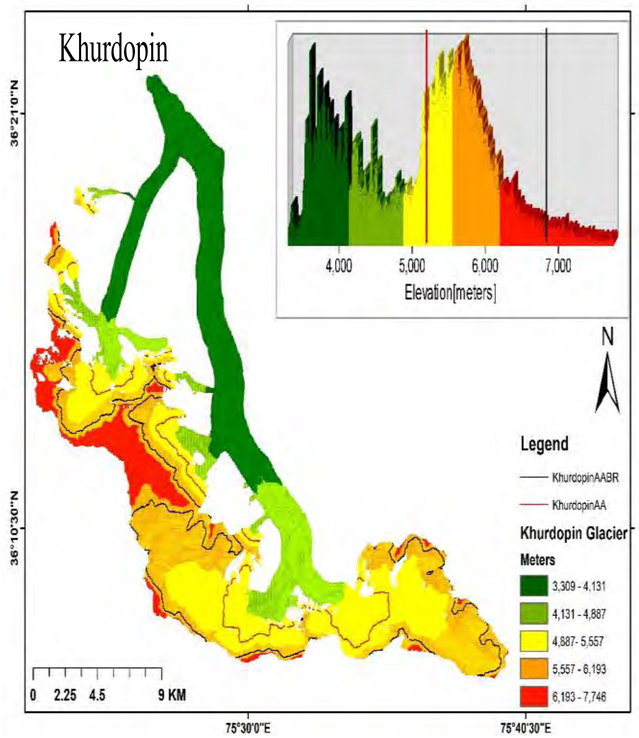


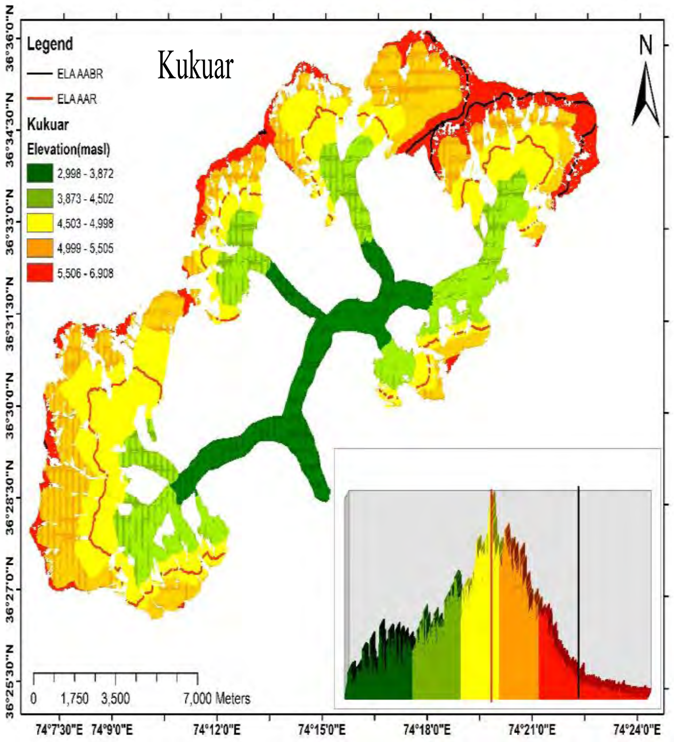
Fig 7: (a) the glaciers outlines, and their hypsometric curvatures derived from SRTM satellite data**(b)** Map of HRB glaciers

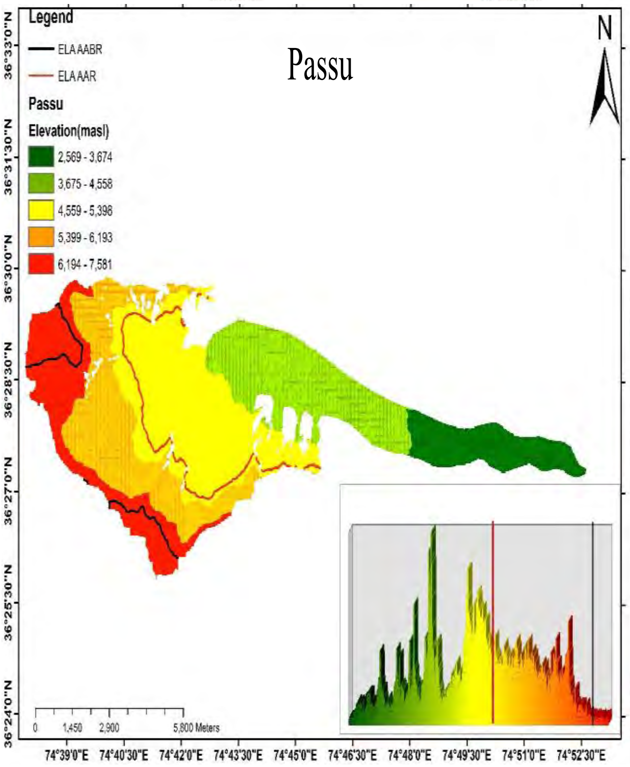
3.5.Calculating a Net mass balance ELA:

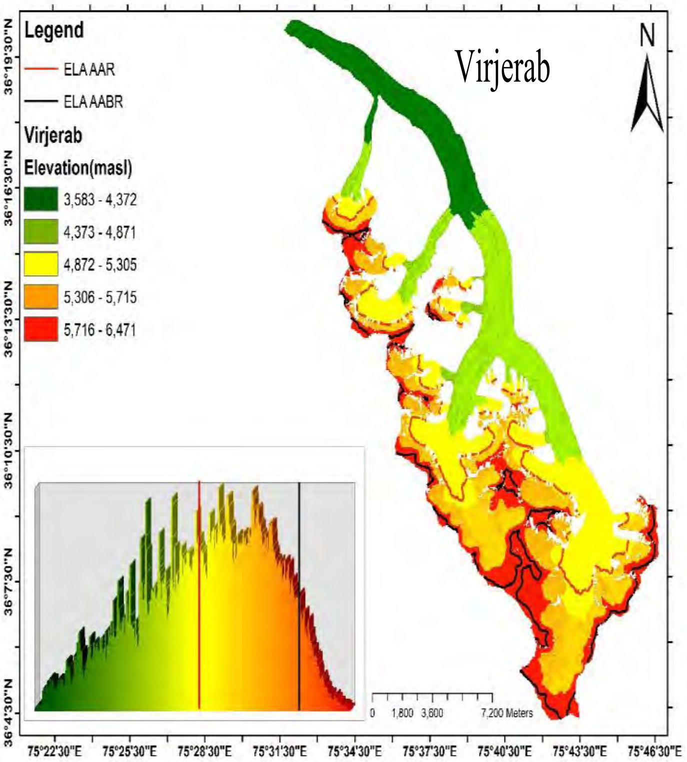
it is assumed these ten HRB glaciers are in steady state with climatic settings and predicted zero net-balance ELAs. Maps of the glacial ice extent and contour lines for the ten major HRB glaciers are shown in Figure 3.6. We applied statistical regression analysis, and it suggests that the zero mass balance of Batura glacier is ∼ 5010 m based on recommended values of ARR (0.6) for mountain glaciers. Similarly, for Hisper and Kukuar Hopper and Khurdopin glaciers. Yazgil glacier ELA for net zero-balance is 5701 m, as opposed to 4808 m for Yenghutzhar; Virjerab 5231, Passu 5014 and 5210 m for Ghulkin glacier.




Khurdopin
4,000
5,000
6,000
7,000
Elevation[meters]
N
Legend
KhurdopinAABR
KhurdopinAA
Khurdopin Glacier
Meters
3,309 - 4,131
4,131 - 4,887
4,887- 5,557
5,557 - 6,193
6,193 - 7,746
0 2.25 4.5 9 KM
36°21'0"N
36°10'30"N
75°30'0"E
75°40'30"E


Legend
ELA AABR
ELA AAR
Kukuar
Elevation(masl)
2,998 - 3,872
3,873 - 4,502
4,503 - 4,998
4,999 - 5,505
5,506 - 6,908
Kukuar
N
0 1,750 3,500 7,000 Meters
36°36'0"N
36°34'30"N
36°33'0"N
36°31'30"N
36°30'0"N
36°28'30"N
36°27'0"N
36°25'30"N
74°7'30"E
74°9'0"E
74°12'0"E
74°15'0"E
74°18'0"E
74°21'0"E
74°24'0"E


Legend
ELA AABR
ELA AAR
Passu
Elevation(masl)
2,569 - 3,674
3,675 - 4,558
4,559 - 5,398
5,399 - 6,193
6,194 - 7,581
Passu
N
0 1,450 2,900 5,800 Meters
36°33'0"N
36°31'30"N
36°30'0"N
36°28'30"N
36°27'0"N
36°25'30"N
36°24'0"N
74°39'0"E
74°40'30"E
74°42'0"E
74°43'30"E
74°45'0"E
74°46'30"E
74°48'0"E
74°49'30"E
74°51'0"E
74°52'30"E


Legend
ELA AAR
ELA AABR
Virjerab
Elevation(masl)
3,583 - 4,372
4,373 - 4,871
4,872 - 5,305
5,306 - 5,715
5,716 - 6,471
Virjerab
N
0 1,800 3,600 7,200 Meters
36°19'30"N
36°16'30"N
36°13'30"N
36°10'30"N
36°7'30"N
36°4'30"N
75°22'30"E
75°25'30"E
75°28'30"E
75°31'30"E
75°34'30"E
75°37'30"E
75°40'30"E
75°43'30"E
75°46'30"E

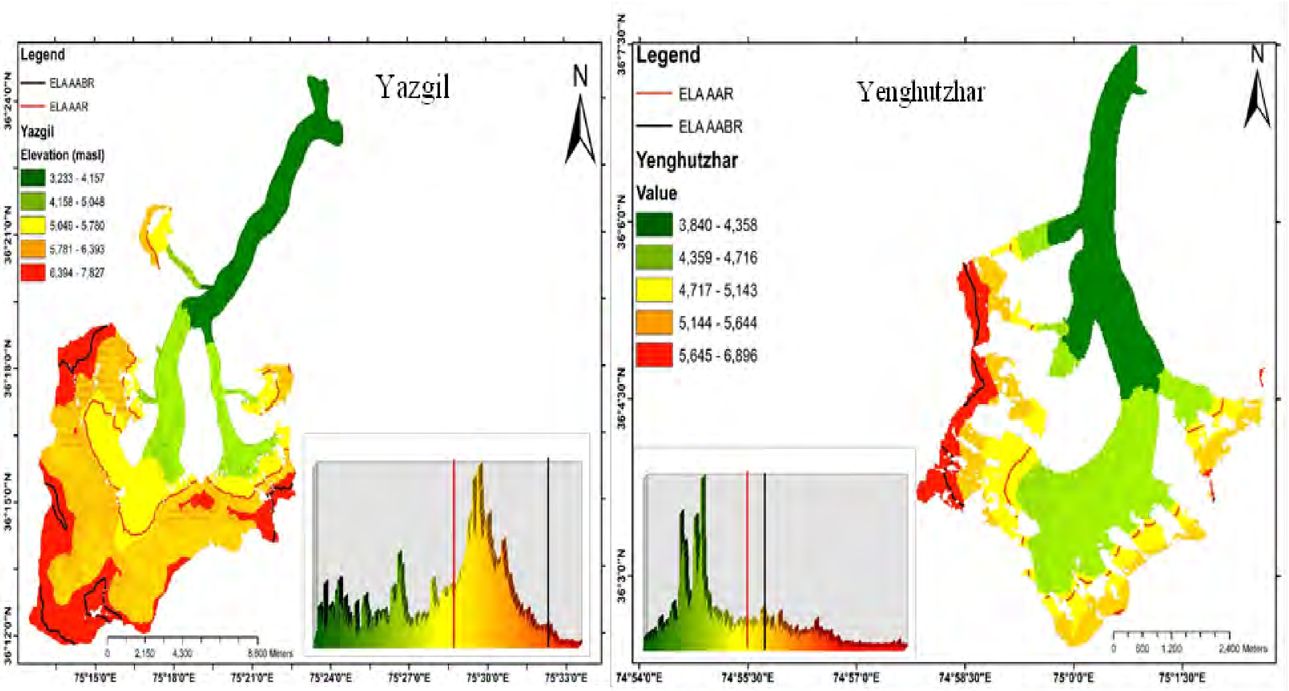


Fig 8: The 10 major glaciers of the HRB of the Karakoram region are depicted on maps with glacier areas and contours that correspond to their corresponding ELAs.

3.6.Discussion:

This study is carried out to estimate the ELA through an indirect method using two recommended ratios AAR (0.6) and AABR (2.24) corresponding to their zero net mass balance for the glaciers in the HRB owing to their high elevation (Pellitero et al., 2015). A decreasing trend in ELA is scene overall but some glaciers show an abnormal trend: the reason to it may be a topography element. Exact reason for it is unknown. The ELA variance between the AAR and AABR approaches suggests that AABR method is more suitable to estimate Equilibrium line altitude of snow-fed and clean-ice coated glaciers. However, because we checked for debris-covered glaciers, the accumulation area balance ratio of ELA requires to be confirmed by using ground observations. A first-order estimator of the sensitivity of the glacier mass balance to changes in ELAs is provided by glacier hypsometry. According to McGrath *et al.*, 2017 a small increment in the equilibrium line altitude might result in a significant dropping in area under accumulation. Regional climatic change, such as an increase in temperature, may, however, change the equilibrium line of glaciers to a threshold level. However, according to above research there is a strong connection between the ratio of accumulation and variation in ELA and each glacier ice extent is associated with its glacier altitude range. However, the reconstruction of the three-dimensional (3D) glacier surfaces has a significant impact on the overall quality of the ELAs.

Chapter 4

Conclusion

Several factors make the Hunza River Basin distinctive (research region) in the Karakoram Himalaya. Firstly, with respective to other regions of Karakoram the glaciated places have a higher mean altitude. Secondly, both clear glaciers and/or ice, as well as glaciers covered in debris, are present in this basin. Thirdly, the mountain populations living downstream are more at risk from the glaciated area. Understanding the topographical surface steadiness and the potential consequence of shifting glacial ice is essential because they can create a havoc if this glacier mass is moved from higher to lower elevations. Ice masses and snow in HRB provide a crucial source of fresh water for those who live downstream. Climate change has a huge impact on ice and snow masses. ELA is a measure of mass balance. Ground studies for the assessment of equilibrium line altitude of many Karakoram glaciers are difficult to obtain owing to the difficult terrain sheltered in glaciers and the scarcity of climatic data over 5000 masl. As a result, we estimated ELAs and reconstructed the relation between glacier and climate data in Hunza River Basin using the hypsometrically controlled accumulation area ratio (0.6) and accumulation area balance ratio AABR (2.24) approaches. This approach provided same AAR rather than steady glacier extent. ArcGIS toolbox was effective, quick, and simple to use when estimating ELAs using AAR and AABR. Moreover, the regenerated three-dimensional glacier surfaces have a considerable effect on the inclusive quality of the ELAs. The technique we employed can rebuild two-dimensional glacier surfaces before reconstructing glaciers in three dimensions to calculate the area over and underneath the ELAs. The AABR approach is suitable to evaluation ELAs of clean-ice and snow-fed glaciers. However, in this study cirque and valley glaciers and highland glaciers. In our analysis, we believed that glacial area far from the ELA—whether it be positive or negative—has a bigger impact on total mass balance than area which is glaciated near the ELA. In comparison to accumulation area ratio, Accumulation area balance ratio, still provides a symbol of the zero net balance, however this is never an exact estimate. It merely shows that the accumulation either increase or decrease is irregular and/or that the pitch is overestimated. The dynamic response technique adapts mountain glacier geometry to future ELA declines by suggesting steady values for AAR and AABR (as an alternative of glaciated area). The field data are not yet in accord with these estimates. To properly understand the relationship between these parameters, an extensive set of field data is needed.

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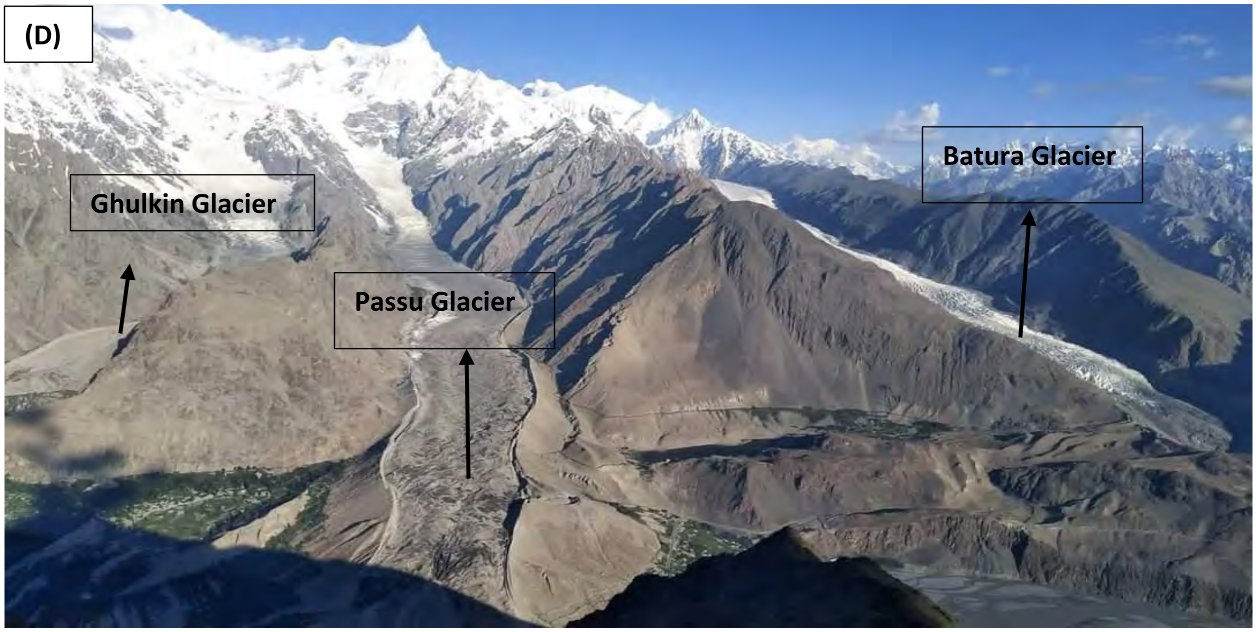
Annexure

Annex:

(A) PASSU GLACIER

(B) HOPPER GLACIER


(C) GHULKIN GLACIER


(D)
Ghulkin Glacier
Batura Glacier
Passu Glacier

(E) YAZGIL GLACIER