Hazard Risk Assessment along the Karambar River in Gilgit Baltistan: A Karakoram Anomaly Affected Region

By

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Dedicated to my exceptional Parents and Family whose tremendous support and cooperation led me to this wonderful accomplishment.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
GIS	Geographic Information System
GLOF	Glacial Lake Outburst Flood
DSAS	Digital Shoreline Analysis System
DEM	Digital Elevation Model
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
MCDA	Multi-Criteria Decision Analysis
HVRA	hazard vulnerability risk assessment
USGS	U.S. Geological Survey
NDSI	Normalized Difference Soil Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
MNDWI	Modified Normalized Difference Water Index
SCE	Shoreline Change Envelope
NSM	Net Shoreline Movement
EPR	Endpoint Rate
PMD	Pakistan Meteorological Department
LULC	Land-use Land-Cover
NASA	National Aeronautics and Space Administration
GEE	Google Earth Engine

ABSTRACT

The northern parts of Pakistan are particularly vulnerable to natural disasters, however comprehensive threat analysis and multi-hazard risk assessment can help to lower the risks. Pakistan's glaciers exhibit the Karakoram Anomaly, with increasing glacier mass leading to ice-dammed lake formation and subsequent outburst flooding. The primary objective of this study was to investigate the changes in river morphology caused by Glacial Lake Outburst Flood (GLOF) events over a span of three decades. To achieve this, the Digital Shoreline Analysis System (DSAS) model and Geographic Information System (GIS) techniques were used, which enable multi-hazard risk assessment. By integrating Multispectral Satellite Imagery, Meteorological Data, and Digital Elevation Model (DEM), various hazards can be accurately mapped. Additionally, field surveys have been conducted to examine the knowledge and experiences of affected individuals, assess the potential GLOF risks, and determine the vulnerability of communities to the effects of such events. The study findings reveal that the Yasin River, Karambar River, and Gilgit River have experienced both erosion and accretion over the period from 1990 to 2020. The accretion and erosion rate for Karambar River during this period was 144.41 m/yr and 140.73 m/yr. Similarly, average accretion and erosion rate for the Gilgit River was 118.97 m/yr and 124.22 m/yr respectively, while for the Yasin River, they were 138.05 m/yr (accretion) and 152.76 m/yr (erosion). Overall, all three rivers have experienced erosion in the last three decades and a systematic approach will be very useful to disaster management authorities for hazard management. Integrated risk management approach will also promote sustainable mountain development.

Keywords: *Natural hazards, Multi-hazard risk Assessment, Climate Change, Glacial Lake Outburst Flood (GLOF), Digital Shoreline Analysis System (DSAS) Model, Karakoram Anomaly*

Chapter 1

INTRODUCTION

1.1. BACKGROUND INFORMATION

The High Asia region's landscape has been significantly altered by climate change, particularly in glacier-rich regions. Gilgit-Baltistan (GB), Pakistan, is situated on the confluence of three mountain ranges—the Himalayas, the Hindukush, and the Karakorum. (Iturrizaga, 2005) These alpine glaciers are a natural, renewable source of freshwater that provide benefits to hundreds of millions of people downstream. Glacial lake outburst floods (GLOFs) are massive discharges of water and debris caused by an unexpected failure of the fragile moraine "dams," which frequently have disastrous downstream effects. A substantial risk of breach exists even for the small glaciers connected to hanging glaciers, which could result in a GLOF. In the past seventy years, twenty glacier lake outburst flood events occurred in Himalayan region which have resulted in significant human and property loss, infrastructure destruction, and damage to forests and other agriculture lands. Over 2500 glacial lakes have been formed in this glaciated domain, and 52 of them have been identified as potentially hazardous from a GLOF perspective, according to ICIMOD's 2005 glacier inventory. (Ashraf et al., 2012)

The Himalaya, Karakoram, and Hindukush (HKH) regions have a stronger trend of temperature increase as compared to global average, according to ICIMOD 2005 inventory of glaciers and glacier lakes. According to inventory, a total of 2420 glacier lakes found in 10 river basins, with Gilgit River basin having the most glacier lakes found (614) In Pakistan's HKH mountain ranges, there were 52 potentially hazardous lakes; 16 of those lakes was found in Karakoram ranges (ICIMOD,2005, Khan et al., 2023)

In the last 200 years, Gilgit-Baltistan has experienced about 35 GLOF episodes (Rasul et al., 2012). Two GLOF incidents took place in the Tehsil Gupis villages of Sosot and Khalti in 1999 (Richardson, Quincey & Luckman, 2014). GLOF occurrences took place in Shimshal Valley in 2000 (Tariq et al., 2014). Six consecutive Glacier flood occurrences from the Ghulkin glacier only occurred from the years 2007 to 2017 resulting in the devastation of the Karakoram highway and local property (Kahlown, M. A., & Majeed, 2003). Khurdopin glacier was the source of the GLOF occurrence. Recent GLOF event occur in May 2021 in Shyok glacier was quite devastating. (A. Hussain et al., 2020)

In the last 200 years, the Hindu Kush Himalayan region has been characterized by GLOF events. They are one of the most significant sub -– 4500 m geomorphological processes at the moment. In the past, ice-dammed lakes formed from 22 tributary glaciers which were flooded by outburst floods from 12 dams in the upper Indus catchment area . (Hewitt, 2005)

Globally, glaciers are known to be retreating, but in northern Pakistan some of the glaciers are growing. This phenomenon is known as the Karakorum anomaly. Discovered between 1997 and 2001, the Karakoram anomaly interests the scientific community the most (Hewitt, 2005). Cryosphere (2013) stated that Karakoram Glaciers shows significant increase since 1960. It has received contributions from a (Belò et al., 2008; Viviroli et al., 2011; Forsythe et al, 2012; Minora et al., 2013; Bocchiola & Diolaiuti, 2013) including, glaciological analysis, such as observations and techniques

De Kok et al., (2020) reported an increase in snowfall to offset the disappearance of glaciers in Karakoram. The variable spatial distribution of glacier elevation variations over the central Karakoram has been the subject of studies on the regional mass balance. These studies also revealed a slight mass gain and loss. Cogley (2011a, 2011b)study shows that Indian Himalayan glaciers have shown negative mass balance since 1974, with few positive one till 2012. In figure 1.1. Geodetic techniques have revealed that the western, central, and eastern Himalayas had volume decline throughout the 2000s, while the Karakorum region glaciers experienced an increase in ice mass. Only one glacier, Siachen, was subjected to the hydrological approach for mass balance estimation between the years 1987 and 1991. Their study contributes to the discussion of Himalayan glacier mass balance estimation utilizing AAR and particular mass balance relationships. When applied to different basins, however, uncertainty in the specific mass balance occurs. Future initiatives should concentrate on developing long-term benchmark glacier networks using approaches that have gained international recognition.

According to the major global emission scenario, the temperature will rise to 5 °C by the end of this century, which is greater than the predicted global average value shows in (figure 1.2). Furthermore, it's projected that the northern portions of the country would have a higher increase in annual mean temperature than the southern regions, which will cause glaciers to melt more quickly.

Anthropogenic activities are primary driver of global warming, and it is likely that they have impacted the global water cycle, according to Intergovernmental Panel on Climate Change (IPCC) 2014 report. Global Glaciers are shrinking because of climate change. Using satellite remote sensing techniques is a useful method typically used to evaluate the mass balance of glaciers. Glacier mass variations can be detected using remote sensing techniques. By using remote sensing data, (Cryosphere, 2013) calculated the mass changes of the Karakoram glaciers.

Effective satellite remote sensing technology can greatly aid in the monitoring of glacier resources. Technology is one of the greatest instruments for locating these glacial lakes and provides significant benefits for quick and accurate glacier lake danger evaluations (Raj, 2010). No doubt that the lives and property of those who live far off from these unstable lakes are under a major threat. The circumstance, along with knowledge that there is possibility of increased harm and loss of life, may calls for a thorough examination of the GLOF danger scenario and response analysis in targeted Himalayan area.

According to (Bishop et al., 2014) (figure 1.3) shows only 50% of the Karakoram glaciers are increasing and may shows positive mass balance condition, while remaining 50% are melting and decreasing like the other glaciers of the eastern and central Himalayas which assumes of linear change through time unsustainable.

Observations and inventory studies done by remote sensing comprise most of the fundamental knowledge of the Karakoram glaciers. Assessment and mapping of glaciers have utilized a variety of methods and techniques. To effectively characterize the scale-dependent parameters and surface processes which govern the dynamics of climate-glacier, advanced geospatial technologies have not yet been utilized.

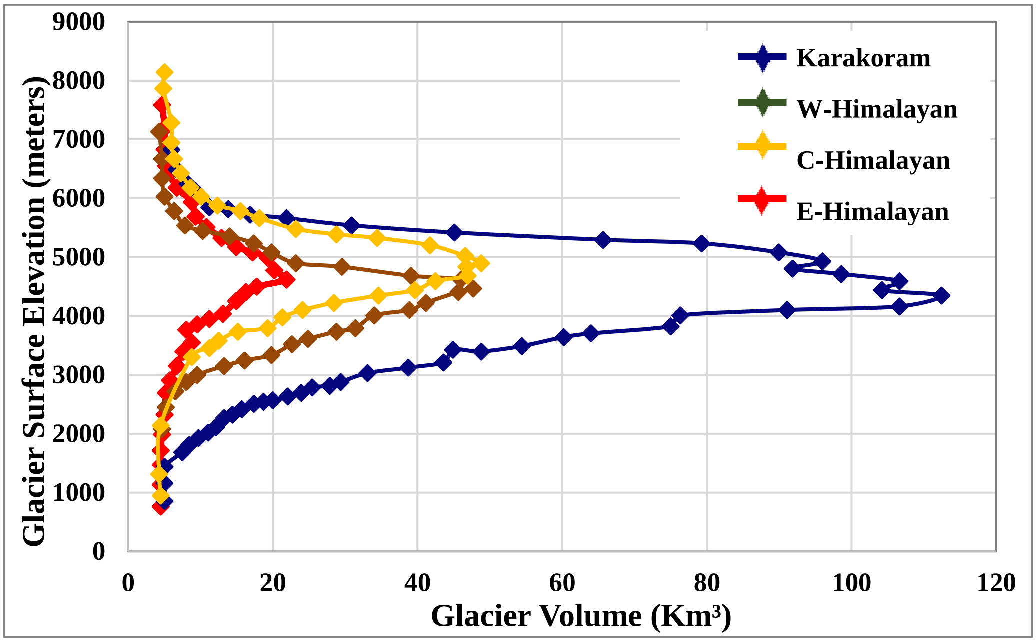

Figure 1.1. Hypsometric distribution of Elevation and volume for Karakorum, Western, Central, and Eastern Himalayas.(Frey et al., 2014)

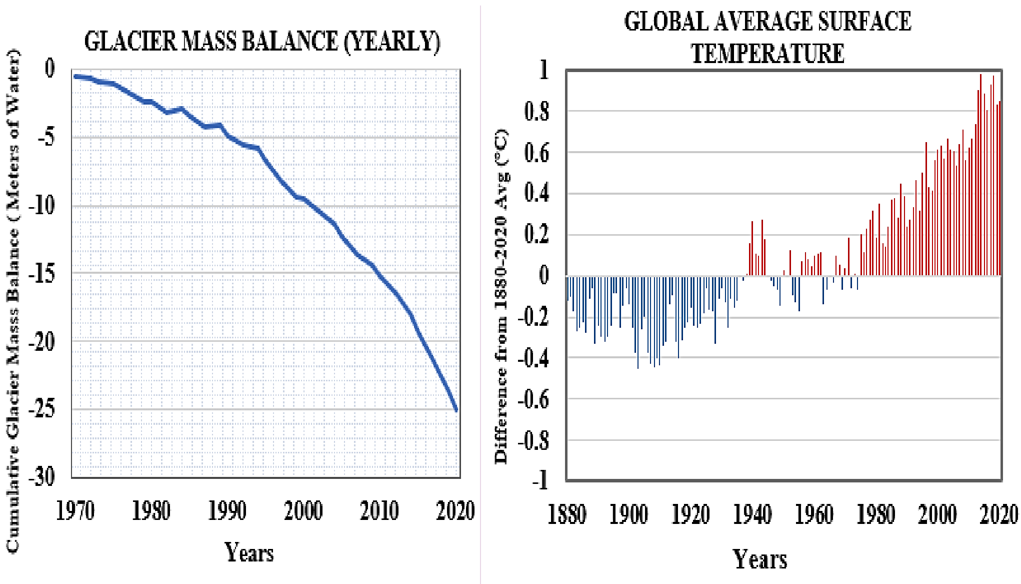

Figure 1.2. Yearly global average surface temperature 1880-2020 compared to the twentieth-century average. The temperature has risen 0.14 degrees Fahrenheit per decade since 1880. (Source: Data from NOAA)

In terms of climate systems, the trajectory of the Westerlies and monsoon both deposit orographic precipitation depend on the topography they pass through. Unfortunately, neither climate reanalysis products nor most regional-scale climate simulations adequately describe or depict the spatial heterogeneity of Karakoram precipitation. Moreover, climatological driving and highly atmospheric circulation distributions over time explain glacier size and mass distributions because these yearly precipitation patterns do not overlap regionally. Upcoming Karakoram ice, snow, and sediment flows, as well as increasing global temperatures, altering wind circulation, and velocity patterns, will all significantly affect the region.

However, due to conflicting and geomorphological impacts, it is unknown to what extent precipitation or these radiative forcing will determine how vulnerable glaciers are in the Karakoram to climate forcing ((Dobreva et al., 2017). Human property and public infrastructure damage are caused by riverbank erosion (Chowdhury et al., 2022). River ecology may be impacted by riverbank erosion (Tha et al., 2022). Attention must be given right away to the locals living in the river valley's fluvial dangers, which are caused by bank erosion (Deb et al., 2012). Fluvial geomorphologists utilize satellite imageries more frequently than ever to track changes in bank lines because of the capabilities, like broad area coverage, a global perspective, and consistent data. Remote sensing and GIS techniques are most frequently used to find spatiotemporal changes in long and dynamic rivers (Hasanuzzaman et al., 2022).

The USGS's widely used Digital Shoreline Analysis System (DSAS) is geospatial model that uses discrete left and right riverbanks to calculate channel transformation rate. It is the most popular tool for analyzing changes in river or coastal bank lines over time using historical datasets. (Rajkumari et al, 2021). Some researchers, including those in the Pakistan is (Siyal et al. 2022), (Isha & Adib, 2020) in Indonesia. (Sheik & Chandrasekar, 2011; Mahapatra et al., 2014; Roy et al., 2018; Bhattacharya et al., 2020; Bhuyan Jamia, 2022) in India in Cambodia (Tha et al., 2022), (Isha & Adib 2020; Abdul Maulud et al., 2022) in Malaysia, (N.A.Thinh et al, 2017) in Vietnam, in Turkey (Kale et al., 2019) and in USA (Hapke et al. 2009) uses Digital Shoreline Analysis System (DSAS) model in the field with success.

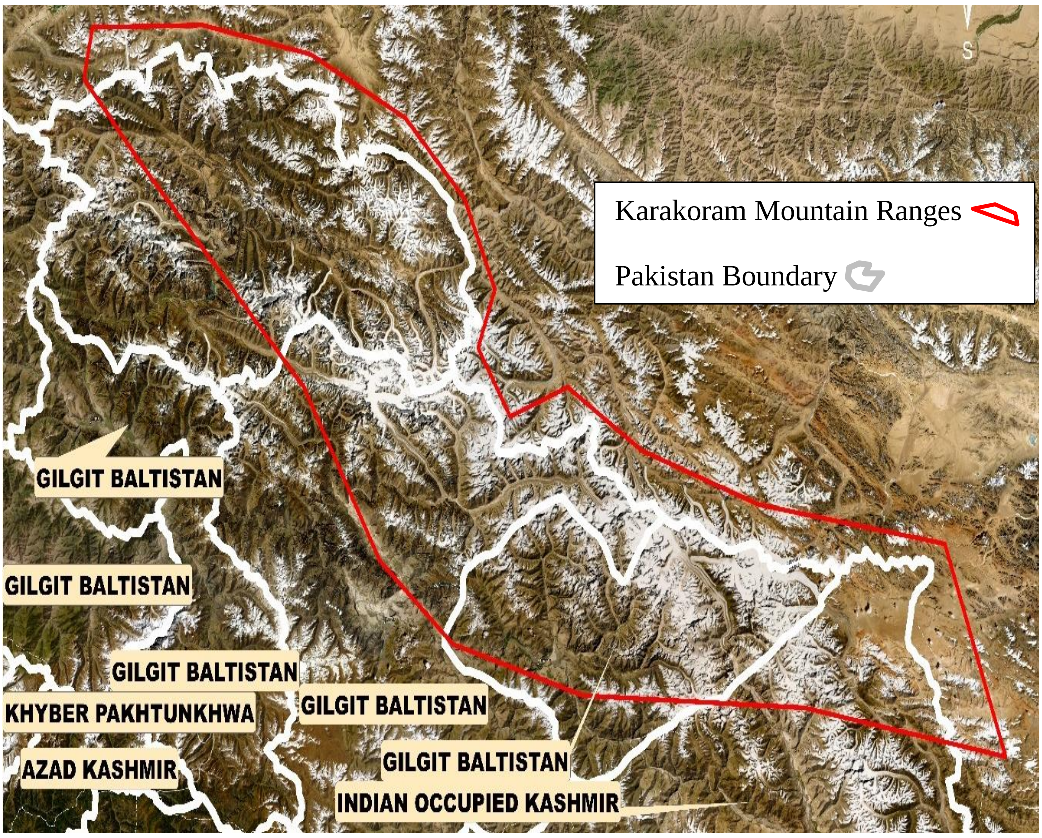

Figure 1.3. Figure shows the Karakoram Mountain Range in Pakistan

1.2 LITERATURE REVIEW

1.2.1. **Glaciers and Climate Change**

Gioli et al., (2014) examines how six settlements in the West Karakoram's mountains perceive and respond to environmental and climatic changes. The area is one of the world's most harsh and inaccessible alpine regions, with frail and complex institutional structures. Due to its significance for water storage and variability, the hydro-meteor-climatological research community considers it to be one of the main areas of research. Community perceptions of changes were examined in the perspective of sustaining life and confronted with multi-driver situations that influence the lives of mountain people.

Ashraf et al., (2012) examined in his research that Mountain systems in Northern Pakistan are vulnerable to environmental pressures due to geographic isolation, limited natural capacity, and lack of suitable alternatives. Their study aims to estimate district-level catastrophe risk and vulnerability rankings. Few studies have looked at how communities in mountainous places perceive danger and how that perception affects how those communities react to disasters and climate change. (Dahal and Hagelman III) In Nepal for example, those who live downstream of a glacial lake were found by to have the low risks perception of the potential Glacier Lake outburst flood occurrence, which left many of them unresponsive to taking mitigation measure against the potential disaster event. It demonstrates that socioeconomic factors influencing glacier lake outburst flood risk perceptions and climatic change depend on the context, which justifies looking into dangerous regions where no previous research of this kind has been done.

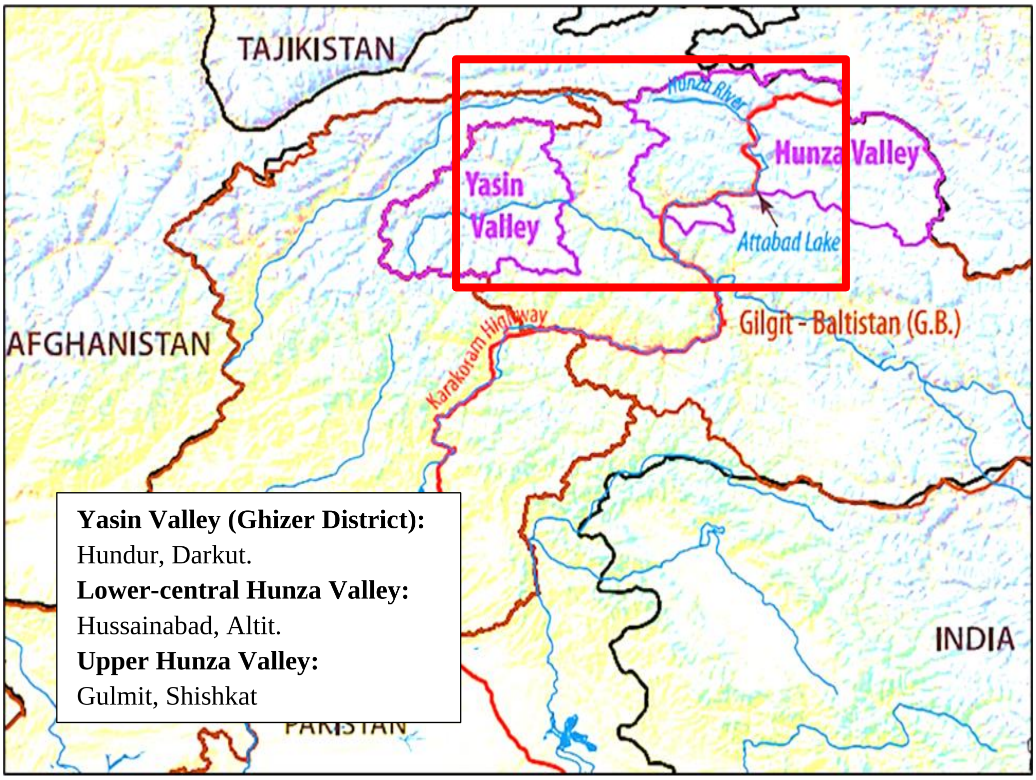

Figure 1.4:This figure shows the Six Settlements in the West Karakoram's mountains (Gioli et al., 2014)

1.2.2. **Glacier melting and risk in Pakistan**

Changing climate has a strong impact on the formation of glacial lakes. From the past 200 years, ~ 35 destructive GLOF events were recorded in Karakoram region (Ashraf et al., 2012). Khadka et al., (2021) uses Multi Criteria Decision Analysis (MCDA) to identify a total 345 of glacial lakes of which 64 glacial lakes were assessed, result shows that seven lakes are highly susceptible to GLOF in the study area.

Time duration for Snow cover melting is getting shorter and mountain glaciers are getting smaller because of global warming, according to Barry (2002). The GLOFs are simply not linked to rapid glacier retreat (A. N. Khan & Khan, 2015; Harrison et al., 2018) since changes in rainfall patterns also play a significant effect. Booni Gole Glacier in Hindukush, which was the source of an outburst flood in July 2010, caused significant damage to agriculture and habitations along with the channel (Rasul et al., 2012). S. Hussain, (2011) assessed that GIS-based geo-hazards assessment model is an effective method for identifying and evaluating current hazards, their dangers, and the vulnerability of mountainous communities.

Badswat glacier was considered the main cause of outburst flood in Karambar valley (Shrestha et al., 2023). Hazards map and hazard vulnerability risk assessment (HVRA) was carried out. From literature, secondary data has been collected (Shah et al. 2019). Flash flooding: erosion, debris flow, GLOFs and earthquakes are considered the major hazards of Karambar valley (Shangguan et al., 2021).

Iturrizaga, (2005) assessed that the Karambar valley had at least six disastrous glacier floods in the 19th and 20th centuries. The geomorphological features that are typical of glacial dams, geomorphological effects of outburst floods and lake basins are highlighted in the Karambar case study. The Karambar valley were sealed by the Chattaboi glacier across a 4 kilometers span shown in (figure 1.5). One of the longest records for this area is the rebuilt Karambar flood chronology, which provides details on past and present glacier oscillations.

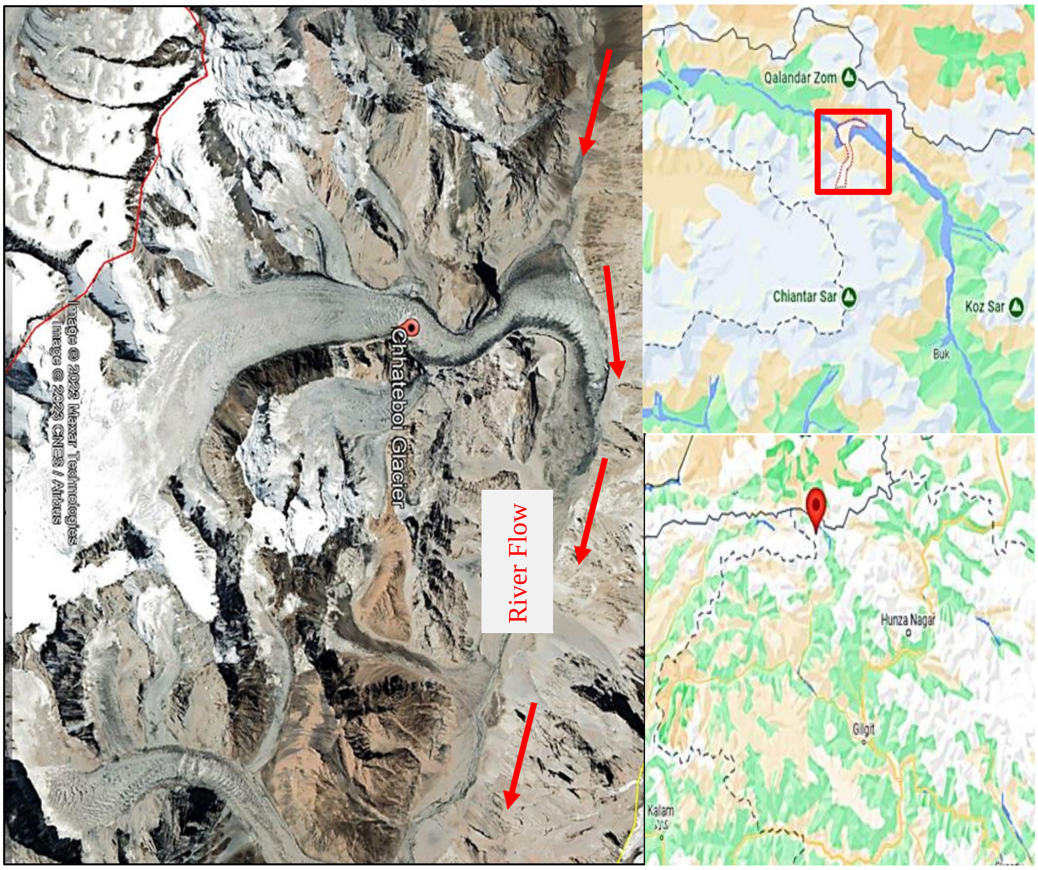

Figure 1.5. Figure shows the total expansion of Chattaboi Glacier in Gilgit-Baltistan, and it is increasing at higher rate as compared to other glaciers in the world.

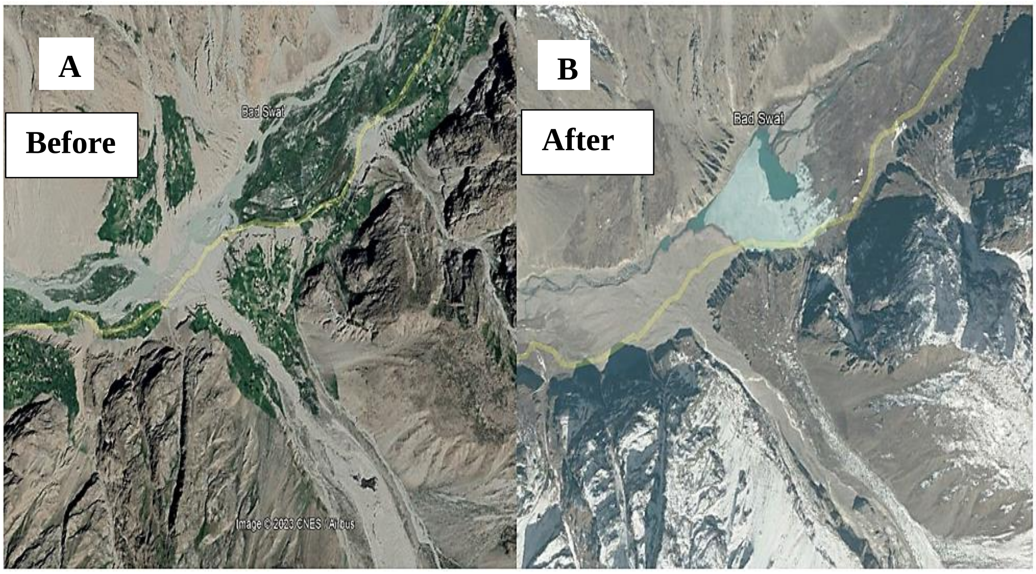

Figure 1.6 (a,b). The above google image shows before and after the situation of GLOF event happened at Badswat River in Ishkoman Valley in July 2018.

GLOFs are also mentioned as a potential threat to mountain communities in Pakistan's National Climate Change Policy. Figure 1.6(a,b) shows On July 17, 2018, a GLOF event originated from the Badswat glacier. The resulting debris blocked the Ishkoman River. It swept four houses down the valley right away and stopped the river from creating a lake upstream. Community behavior in times of emergency and disaster can be significantly influenced by risk perception. Many places, particularly the ice-capped mountainous regions, have become more susceptible to the high risks brought on by the changing climate because of rising temperatures caused by global warming (Shahab et al., 2017).

Anwar & Barcha, (2020) explained that Badswat GLOF from the Badswat glacier caused an artificial lake 1140 meters long and 750 meters broad in less than an hour, lasting 12 days with occasional pauses between events. Their research provides valuable lessons for the future. Yasmeen & Afzaal, (2017) map the consequences of climate change in the Karakoram ranges and Hindukush ranges using data from remote sensing and GIS. They found that the Yazghil and Darkut glaciers are retreating and have been steadily losing mass due to an increase in the area's mean temperature. Shangguan et al., (2021) analyzed the sequence of events of July 17, 2018, when glacier debris flows choked the Immit River in the Hindu Kush Karakoram Range, using satellite remote sensing and field data. Their research is valuable for understanding how glacial disaster chains form and developing mitigation strategies to lower the dangers to vulnerable downstream/upstream residents.

1.2.3. **Application of satellite remote sensing and GIS in GLOF study**

Shafiq et al., (2020) used Geographic information technology and remotely sensed data to undertake watershed management studies on the upper Indus basin. Using digital elevation models, topological feature extraction was examined. The SRTM 30m DEM has been demonstrated to be more accurate. For challenging ridge matching, the delineated watersheds were manually matched to optical Landsat 8 optical imagery. It has been claimed that the computed region from all three Dem data was mostly similar. Our understanding of the hydrologic response and water management in the Gilgit basin in the upper Indus catchment has significantly increased because of their work.

Geographical Information System (GIS) based techniques used for assessment of multiple hazards. Flow magnitude assessment matrix were derived for assessment of potential glacier lakes (M. Lei et al, 2020). Their final map corresponded to the potential urban development suitability map of the study area as well. This method can be helpful for natural hazard management to the planners and governmental authorities. Skilodimou et al., (2019) Mapping, monitoring, and estimating snow cover is labor-intensive and difficult, but optical satellite imagery allows for accurate mapping. NDSI was used to map snow cover using multispectral datasets. As a result, it is possible to identify snow cover that are receding at high, medium, and low rates by combining GIS and remote sensing approaches (Zamir & Masood, 2018).

Climate change and human activities are the main causes of receding Glaciers on Earth, and in northern Pakistan, GLOF is considered one of the most common hazards. In their study, the 25 temporal variations of Darkut glacier lake were mapped and modeled using survey data, remote sensing, and GIS techniques. Their study's findings will be applied to the development of risk management plans, readiness methods, and risk reduction techniques for GLOF's threats. (Amin et al., 2020).

The Indus River system's main watershed, Northern Pakistan's glaciers and mountainous regions, are prone to rapid changes in land cover due to human activity and climate change, which have the potential to negatively impact environmental quality and increase hydrometeorological risks. Ali et al., (2019) Understanding the hydrological processes in a basin requires performing a watershed morphometric analysis. Pakistan's Hindu Kush and Karakoram Mountains are home to the Gilgit River Basin. The Gilgit river basin's morphometric evaluation was done. Geological and field data are combined with remote sensing data from Sentinel 2A image, For the morphometric investigation of the Gilgit Basin, the Global Elevation Model (ASTER-GDEM) was combined with data from additional sources. The results demonstrate that there is a large potential for stream discharge throughout the whole drainage basin region, which reflects the semi-stabilized stage of the fluvial geomorphic cycle. (Ali et al., 2019).

The study on Pakistan's River Indus Delta used the remote sensing data, DSAS model, and ESRI software to quantify shoreline alterations in the Indus delta. Between 1972 and 2017, the overall shoreline change was measured using Net Shoreline Movement (NSM), and statistical parameters EPR and LRR were used for calculating the rate of shoreline change. Results show Accretion of 1 to 160 m/year. In year between 1972-2017, The delta's shoreline shifted 860 meters landward. The research suggests using mitigating tactics to protect the shoreline of the river Indus (Altaf A. et al, 2022).

Debnath et al., (2023) compare the changing land use and landcover of the riverbank assessed using the model developed by CA-Markov with the changing planform of the Brahmaputra River using Digital Shoreline Analysis System (DSAS). The erosion-accretion rate of the river was discovered to be higher in earlier periods than in more recent ones. More erosion occurred on the left bank than the right, indicating that the river is moving left. Using the real Bankline and predicted Bankline, as well as the actual LULC map and anticipated LULC map, the degree of accuracy was confirmed.

The Karakoram expansions are not refuted by climate change or atmospheric warming but may be explained by warmer temperatures and increased moisture transport to higher altitudes. The main flows of the Indus and Yarkand rivers are dominated by Karakoram glacial meltwater, and 200 million people in the drylands nearby depend on them as resources and threats. However, if the expansions reflect redistribution of ice downslope, climatic warming may accelerate depletion. The study investigated the variations of the Karambar, Yasin, and Gilgit Rivers from 1990 to 2020 using satellite images and DSAS application. Results showed that Yasin River experienced both erosion and accretion, average EPR of 120.00 m/yr (accretion) and 113.05 m/yr (erosion), the average NSM between 1990 and 2020 is 138.05 meter (accretion) and 152.76 meter (erosion). Using EPR statistics, the long-term mean erosion rate for karambar river is 123.4 m/yr (accretion) and 128.80 (erosion) and average NSM between 1990 and 2020 is 140.73 m/yr (accretion) and 144.41 m/yr (erosion) and for Gilgit river shows an average EPR of 109.09 m/yr (accretion) and 104.03 (erosion) and average NSM between 1990 and 2020 is 118.97 m/yr (accretion) and 124.22 m/yr (erosion). Karambar river shows the highest accretion and Yasin River shows the highest erosion in three decades.

The DSAS application also included exceptional and scientific features for secondary indicators. The examination of shoreline change may serve as a backdrop for further research into causes and workable solutions. Climate change has increased the risk of slope-dependent processes and lake formation, making this dilemma significant in the Ishkoman region. It is required to perform hazard and risk assessment assessments, establish risk mitigation methods, and carry out extensive research on hot spot GLOF lakes in different river basins to give a comprehensive policy framework. For hazards assessment and monitoring of GLOF areas, it is necessary to use methods like remote sensing and hydrodynamic modelling in conjunction with ground surveys to increase risk reduction and early warning.

1.2. PROBLEM

Pakistan is among the top ten countries to be highly affected by climate change, according to the statistics of the global vulnerability index. Large portions of Pakistan's population are extremely poor, making them particularly vulnerable to the negative effects of climate change. Rasul et al., (2012) stated that the GB region has been feeling the effects of global climate change at an ever-increasing rate; it is the true climate change hotspot. The most sensitive indicators of global warming are snow and glaciers, which have an immediate impact on glacier health and the amount of melt that comes from them.

In addition, the extreme aridity of the GB environment and the sparse vegetation on the slopes cause runoff when there is a lot of precipitation on the slopes and gorges. Debris flows are likely to occur because the slopes have a lot of exposed debris from weathering, slope degradation, glaciers. These events have resulted in the destruction of roads, houses, lands, and livestock, which has had a wide range of negative effects because they have deprived already economically precarious communities of their means of subsistence.

GLOF from Badswat glacier occurred on July 17, 2018, caused an artificial lake, submerging houses, schools, orchards, agricultural land, and a road, leading to evacuation of three villages downstream. Main aim of research was to calculate the impacts of climatic changes on the Glaciers of Pakistan. This study investigates how communities in Pakistan's mountainous region perceive the risks posed by climate change and GLOF to fill the knowledge gap in this area.

1.3. OBJECTIVES

The Objective of this research were:

1. To examine the Changes in river morphology due to GLOF events over the time span of three decades and future risk assessment of the surrounding communities in study area.

Chapter 2

MATERIALS AND METHODS

2.1. STUDY AREA

Karambar valley lies at Eastern Hindukush (36°52′46″N 73°40′28″E). The Karambar valley starts from Karambar pass and ends at the Immit village located in Ishkoman valley. Topographically, the course of the valley varies significantly from place to place. The region has dry temperatures and record shows rainfall of less than 200 mm per year. The annual temperature ranges from 20 to -15 degrees Celsius. According to the Pakistan Meteorological Department (PMD), monthly average rainfall ranges from 4 to 26 millimeters, and the high rainfall period is in June and July. The Ishkoman and Badswat Rivers saw an increase in stream flow because of melting snow and glaciers and high temperatures. Glaciers present in the study area are highly susceptible to climate change effects and can cause landslides and GLOF events in the future. Common hazards of Ishkoman valley are GLOF, Earthquake, landslides (rock falls, debris falls etc.), mud flow and erosion.

The study area used in research, and it includes three rivers of Ghizer district, Gilgit river, Yasin River and Karambar river. Ghizer is one of the ten districts of Gilgit Baltistan. Figure 2.1 shows It is blessed with snow-capped mountains, diverse plants, attractive villages, and crystal blue lakes.

Ghizer valley lies between Hindu Kush and the Karakoram Mountain ranges. Why this study area; because it consists of number of highest glaciers (more than 7500 m) in Pakistan, and it is also known as the Karakorum anomaly affected region which means that at that part the glaciers are increasing.

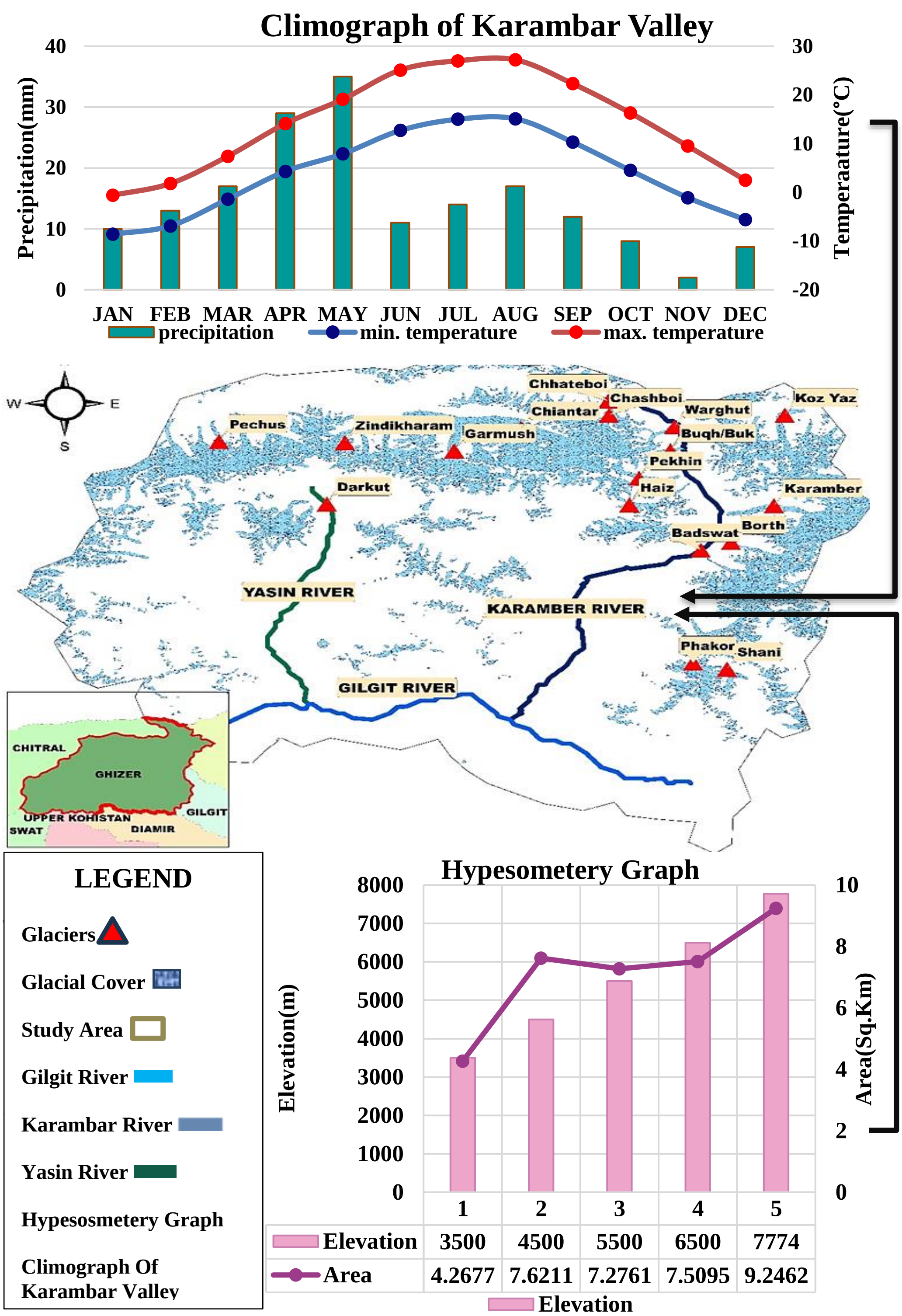

Figure 2.1(a,b,c). The study area map of Karambar valley shows rivers of Yasin, Karambar and Gilgit originating from the glaciers in the north. 2.1B shows the Hypsometry Graph, 2.1C shows Climograph and increasing trend of temperatures in Gilgit Baltistan region.

2.2. METHODOLOGY

2.2.1. Methodology Flowchart

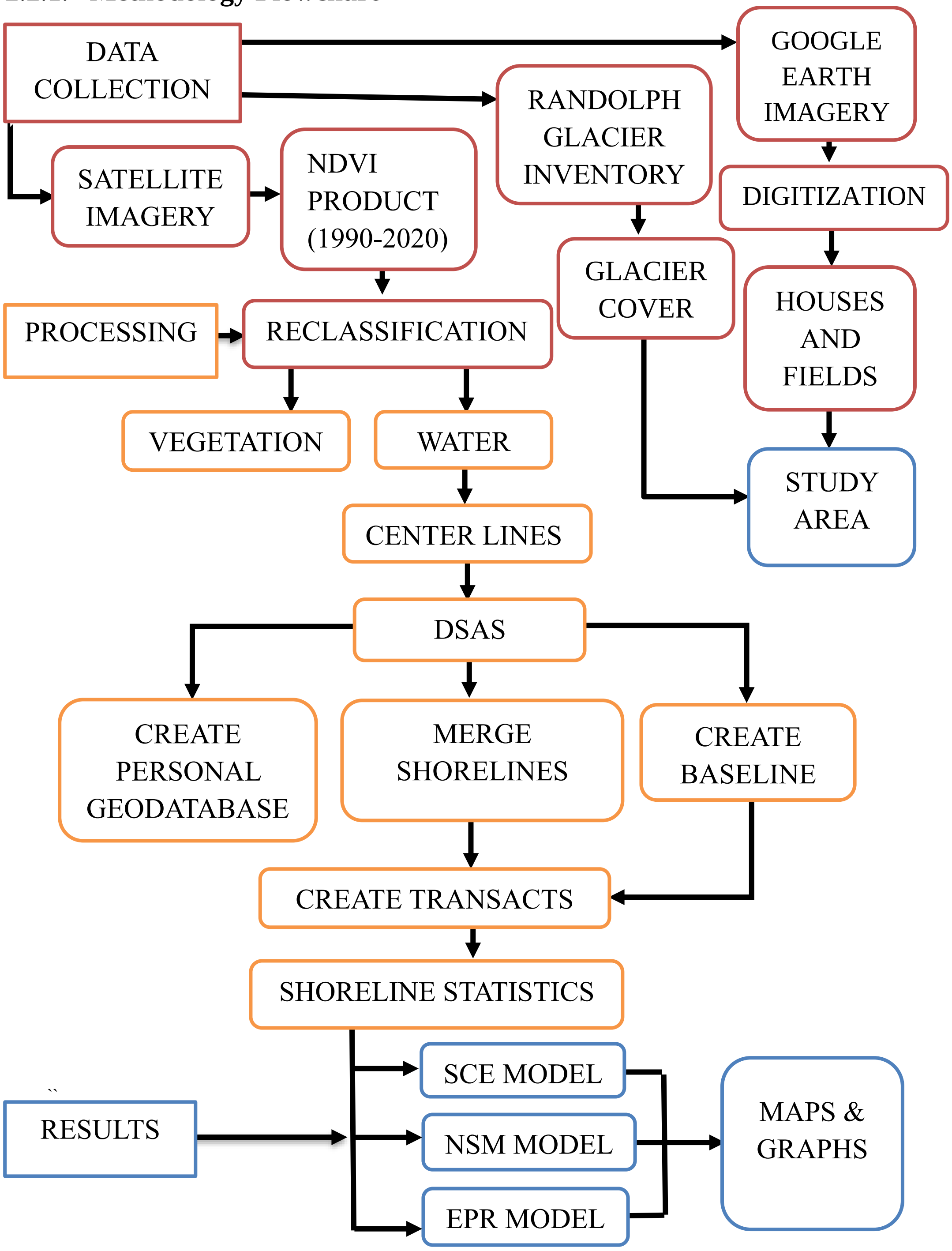

Figure 2.2. The flow chart explains the methodology used in this research. The red color shows what type of data is used, green color shows the processing techniques and blue color shows the result part.

2.2.1. **Datasets**

Table 2.1. Table shows the datasets used in the present study which includes raster data, satellite imagery, NDVI products and Field Survey Data.

DATA	DESCRIPTION	SOURCES	TIME PERIOD:
RASTER DATA	• GLACIER INVENTORY (NASA)	National Aeronautics and Space Administration (NASA)	---
SATELLITE IMAGERY	• LANDSAT 4 and 5 Thematic Mapper • LANDSAT 7 enhanced thematic mapper. • LANDSAT 8	United States Geological Survey (USGS)	From 1990-2020 (Data of some years were missing)
FIELD SURVEY DATA	Field Survey Conducted For Flood Affected Villages in Ishkoman Region.	Collected Through Field Survey	---
NDVI PRODUCTS	NDVI Product of LANDSAT 4,5,7,8 and SENTINEL-2. Having 0-10% Cloud Cover	Google Earth Engine (GEE)	From 1990-2020 (Data of some years were missing)

2.2.2. **Landsat Images**

Images from the Landsat TM, ETM+, and OLI satellites downloaded using the cloud computing system Google Earth Engine (GEE). The photos span the years 1990 to 2020 and have a 30 m spatial resolution. Radiometrically rectified Level 1 data of Landsat satellite images projected in the Universal Transverse Mercator (UTM) coordinate system (42N zone) and used in this study. The Landsat data that were used in this instance were typically from the months of March through May. The Landsat images from this period showed less persistent snow cover.

2.2.3. Sentinel-2 imagery

10m multispectral 13-band imagery from Sentinel-2, produced instantly. Imagery Layer, which is accessible for visualization and analytics, directly accesses Sentinel-2 on GOOGLE EARTH ENGINE. This imagery layer could be used for a number of things, not just one or two but also for monitoring the environment including monitoring vegetation health, land cover, land use changes, and deforestation.

By default, the most recent, less than 10% of clouds, image for any location is shown. Custom filtering enables the viewing of any image that has been made accessible in the last 14 months. Filtering can be done using Tile ID, Estimated Cloud Cover, and Acquisition Date. NDVI Colormap (Normalized Difference Vegetation Index with Colormap), which is the default rendering, is calculated by given formula.

$$NDVI = \frac{(B8-B4)}{(B8+B4)} \qquad \text{Equation (2.1)}$$

2.2.4. Glacier Inventory Data

Since most glacial lakes were found at higher altitudes and therefore challenging to physically assessed, the thorough examination, evaluation, and observation of many glacier and river aspects is supported using geographic information system and remotely sensed tools and techniques. Randolph Glaciers Inventory (RGI), which excludes ice sheets, is a nearly global assessment of glacier outlines. On remote data, such as satellite images, it is simple to identify the assessments of some crucial characteristics of glaciers. Most lakes and rivers are located at higher altitudes, making it challenging to reach them for in-depth assessments physically, investigations, mapping, and monitoring. It also requires a lot of time, human and financial resources, so the data from remote sensing and GIS techniques are very helpful.

2.2.5. Digital Elevation Model data (DEM)

The topography information can be adequately represented by SRTM DEM due to its high vertical accuracy. There are some information gaps in that version due to radar shadow, overlap, and poor interferometric synchronization; however, most of these gaps cover relatively rocky high-mountain terrain, with almost none covering relatively flat areas like tongues of glaciers and the region around river. A few of the rivers Bankline share comparable spectral properties during the mapping process were easily confused with mountain shadows. Terrain shadows were reduced using slope and by using digital elevation model shaded relief maps were produced.

2.2.6. **Vegetation indices data**

The NDVI technique is frequently used to evaluate changes in vegetation dynamics and its relationship to various climatic conditions, particularly temperature and precipitation, which are thought to have the greatest impact on vegetation cover. NDVI product of Landsat and Sentinel images were used for year 1990 to 2022 to examine the changes in vegetation and data is available on the GEEs Data Catalog.

The range of NDVI values is (-1) to (+1). A value near to positive 1 (+1) indicates the maximum likely green leaves density, while a value closer to (-1) indicates no flora.

$$\text{NDVI} = \frac{(NIR - RED)}{(NIR + RED}$$ Equation (2.2)

RED shows the spectral reflectance in red area (band), while NIR Band shows the spectral reflectance in near-infrared regions, and. The spectral reflectance of Bands 4 and 5 was used for Red and near-infrared respectively, in the NDVI of Landsat-5 and Landsat-8. And Bands 4 and Bands 8 were used for Red and NIR, respectively for Sentinel 2 imagery.

2.3. METHODS

The temporal change of glacial lakes is tracked using free Landsat and Sentinel satellite images. When extracting rivers from satellite data, commonly used indices include (the MNDWI) modified normalized difference water index and normalized difference water index (NDWI). High-resolution remote sensing data, the Digital Terrain Model (DEM), and free software like ArcGIS.

Participatory quality control was needed to address any remaining inaccuracies in the automatic mapping of river channels, such as mountains shadow and partially moving streams. The study focuses on potential changes in river morphology caused by GLOFs in the future. The surveys were carried out and included cross-sectional river profiling, evaluation of flood areas, The surveys comprised cross-sectional river profiling. Maps depicting changes in land cover and the identification and historical demarcation of lakes (Glacier Lakes) were done using remotely sensed data (Landsat) which was obtained from Google Earth Engine (GEE). DTM a Digital Terrain Model from SRTM of 10meter spatial resolution was used to locate the rivers and bound to the region of interest.

In this study, the rivers were identified using the (McFeeters, 1996) suggested Normalized Differential Water Index from 1996. In addition, the results of the NDWI were validated using the Modified Normalized Water Index (MNDWI). Water is present when the NDWI readings, which range from -1 to +1, are positive. Most of the water features have values that are near +1. Those values that are closer to -1 indicate bare soil, land features, and vegetation. The following equation is used to calculate NDWI:

$$\text{NDWI}= \frac{B3-B5}{B3+B5} \qquad \text{Equation (2.3)}$$

McFeeters, (1996) were unable to differentiate between built-up and water features in certain locations where soil and water bodies coexist. In this index, the Near-infrared band has been replaced by the shortwave-infrared band. Because of its high spectral reflectance in green band & mid infrared band, Modified Normalized Water Index assesses water bodies details from targeted area accurately. Like NDWI, even though a threshold value for the Modified Normalized Water Index was assigned as (0), however manual editing of water channels produced a more précised and accurate results (Agarwal et al., 2013). The formula for MNDWI is given below:

$$\text{MNDWI} = \frac{(GREEN-MIR)}{(GREEN+MIR)} \qquad \text{Equation (2.4)}$$

To map the rivers, GEE photos were used as a reference image to extract river’s boundaries and NDVI products and google earth pro used as base map for accuracy assessment.

2.3.1. **Measuring River Channel Changes/ Assessment of bank line shifting rate**

US Geological Survey developed a Digital Shoreline Analysis System (DSAS), is a powerful tool for monitoring shoreline change in mountainous areas. DSAS uses digital elevation models (DEMs) to compare shoreline positions from different time periods and generate shoreline change rate maps. This allows researchers to detect changes in shoreline position over time and assess the impact of various forces, such as sea-level rise and anthropogenic activities. DSAS is especially useful in mountainous areas, where shorelines can be difficult to map without the use of digital technology. The system can also be used to monitor shoreline erosion, sedimentation, and other forms of shoreline change in mountainous areas as shown in (figure 2.3). Additionally, this data can be easily used for assessments of the impacts of climate change and inform management decisions. The system also allows users to determine how much of the shoreline has changed over time.

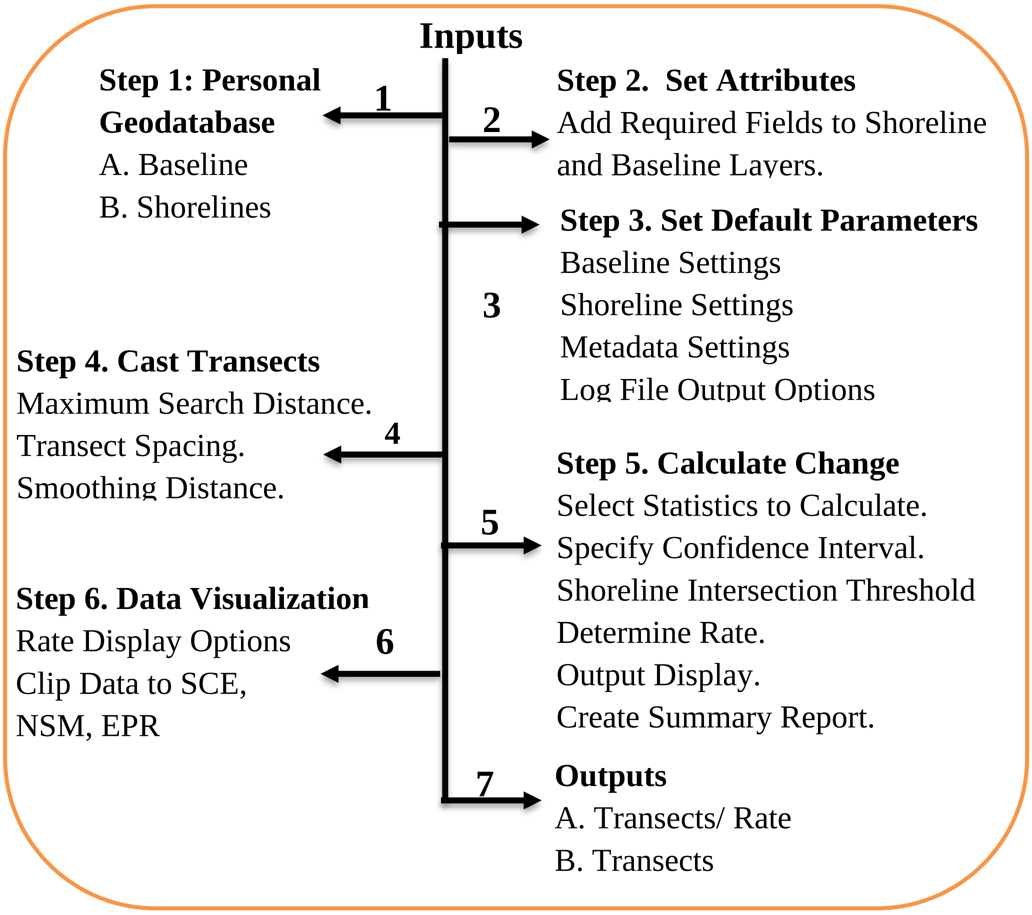

Figure 2.3. DSAS workflow diagram.

From the start of the baseline through its conclusion, each segment is identified by its unique ID. If the baseline is segmented, DSAS uses this variable to arrange the transect lines in a logical order. In table 2.2 there is multiple analysis which can be performed using DSAS, some of which are given below.

Table 2.2. Table shows what type of analysis can be done using digital shoreline analysis system DSAS.

Type of Analysis	Description
Shoreline Extraction	Tools for extracting shoreline positions from georeferenced imagery.
Shoreline Change Analysis	Comparison of shoreline positions over time to assess change, erosion, accretion, or stability.
Statistical Analysis	Calculation of metrics such as average change rates, standard deviations, confidence intervals, and regression analysis.
Uncertainty Analysis	Assessment and quantification of uncertainties in shoreline change measurements.
Visualization and Mapping	Generation of maps, charts, and graphs to visualize shoreline change data.
Long-Term Shoreline Change Analysis	Analysis of shoreline change over extended periods to identify long-term trends and patterns.
Profile Analysis	Creation of cross-shore profiles to examine elevation changes and coastal morphology.
Hotspot Analysis	Identification of areas of concentrated shoreline change or susceptibility to erosion or accretion.

The first step is to create a geodatabase in ArcGIS and the unit which data is stored is meters an impersonal geodatabase which we have created in personal geodatabase can be accessed from ArcCatalog and all the data is stored in that Geodatabase. First, baseline should be created and must meet the requirement of baseline attributes which are shown in the given table. As the baseline was the center line of water of year 1990 so the attribute field should be filled according to the user guide of digital shoreline analysis system. The baseline should be in projected coordinate system must be a single line or consist of election of segments.

Shoreline should be created and must meet the requirement of shoreline attributes which are shown in the given table. The shoreline was created from vector data of water channel. The water channel was extracted from NDVI products and then after some manual processing and editing the water channel was extracted for year 1990 to 2020, then the water channel was in raster, so it is converted into vector format and after that center line of water channel was extracted by using ArcGIS tools.

The river line has been used as baseline and shoreline and for baseline 1990's center line used as baseline for all 30 years data. For creating shoreline database all the attributes which were given in user guide of digital shoreline analysis system should be fulfilled and followed to avoid any errors. In changed-rate analysis, all the shorelines used should be in a form of single shoreline and stored in a database. DSAS automatically draws transects which should be perpendicular to baseline. The user can specify the length and transect spacing. For this research, a transect spacing of 500 meters with the ability to cut transects at the furthest river extent was selected. The orientation of transects depends on the position of baseline. The trend of shoreline to baseline affects the angle at which the transects intersects and affects the rate of shoreline change.

As the baseline and shoreline have been created in DSAS start calculating the intersect distance which was given 500 meters with the ability to cut transect at the furthest river extent. Determining trend output and creating a summary report. In this research, shoreline change envelope (SCE), end point rate (EPR) & net shoreline movement (NSM) have been done by the help of user guide.

NSM is defined as that for every produced transect, the distance between the shoreline that is the youngest and the oldest. SCE tells the distance; it tells the greatest distance among all the transects and the value is always positive. Endpoint rate EPR provides information on the separation of coastline movement between the newest and oldest bank lines, and it only required 2 shoreline dates.

$$EPR = \frac{\text{Distance of bankline movement}}{\text{Time between most recent and oldest bankline}} \qquad \text{Equation (2.5)}$$

$$NSM = (SPt - SP0) - (L - S) \qquad \text{Equation (2.6)}$$

Where:

SPt is the shoreline position at time t.

SP0 is the initial shoreline position.

L represents the total length of the Baseline.

S is the length of the initial shoreline segment.

$$SCE = Max(SP) - Min(SP) \quad \text{Equation (2.7)}$$

Where:

Max (SP) represents the maximum shoreline position observed within the study area.

Min (SP) represents the minimum shoreline position observed within the study area.

The EPR model has been implemented using two years of data sets separately, which are to calculate the accretion and erosion rate of riverbank and spatial temporal changes of those three rivers.

Table 2.3. The table shows how much year data is being used erosion and accretion statistical analysis is done on Gilgit, Karambar and Yasin rivers.

Year	Spatial-Temporal Changes (Erosion and Accretion rate)
1990-2020	Spatial-temporal analysis for the Gilgit, Karambar and Yasin Rivers

Chapter 3

RESULTS AND DISCUSSIONS

The Normalized Difference Vegetation Index (NDVI) is used to observe changes in vegetation dynamics, its relationship to various climatic conditions, particularly temperature and precipitation, which are thought to have the greatest impact on vegetation cover. From 1990 to 2020, the snow cover is decreasing and melting due to rise in temperature, while vegetation cover is decreasing, and urban growth is visible. Google Earth pro was used to vectorize houses and fields. Three statistical values are determined by DSAS: NSM, SCE, and EPR. NSM is the separation between the oldest and youngest shorelines; SCE is the separation between the two farthest shorelines.

Rehman et al., (2014) Flood events have been affecting the Karambar Valley for past 170 years, the Karambar riverbank shifted at an average EPR of 123.4 m/yr (accretion) and 128.80 (erosion) and average NSM between 1990 and 2020 is 140.73 m/yr (accretion) and 144.41 m/yr (erosion). For Gilgit River an average EPR of 109.09 m/yr (accretion) and 104.03 (erosion) and average NSM between 1990 and 2020 is 118.97 m/yr (accretion) and 124.22 m/yr (erosion) is calculated. There are some river segments that are eroding even though the average shoreline rate indicates that accretion is the predominant tendency. Yasin River shows an average EPR of 120.00 m/yr (accretion) and 113.05 m/yr (erosion), the average NSM between 1990 and 2020 is 138.05 meter (accretion) and 152.76 meter (erosion). There are some river segments that are eroding even though the average shoreline rate indicates that accretion is the predominant tendency.

Communities in the northern glaciated region are particularly vulnerable to natural disasters since there is no institutional system in place for coping with and being ready at the village level. Local communities typically use self-help techniques to address such events. Specialized education and capacity-building in mitigation of hazards and risk management are needed to address the amount of climate change's influence on the glacier surroundings, particularly in GLOF-susceptible regions. Target communities and important stakeholders must be made more aware of risk reduction and hazard preparedness.

3.1. RISK ASSESSMENT AND MITIGATION

Most respondents in Ishkoman Valley consider glacier surges, landslides, and flash floods to be the primary natural hazards. A few include river erosion and earthquakes. Riverbank erosion, Flood, and landslides are examples of an interconnected hazards. The strength of flooding may hasten the erosion of rivers and, in some cases, result in the formation of landslides. Flash floods, according to Ishkoman survey respondents, typically occur from spring through the last month of summer, although the first one was reported in January 2008. And my recent visit to Ishkoman valley and the survey conducted by a team shows that most respondents considered flood to be a major hazard in Ishkoman valley. Figure 3.1 shows how disasters have negatively impacted them.

Although rainfall does not pose a significant threat to the region, it does create a risk of mass movement or landslides. During the rainy season, such occurrences frequently cause Karakoram- Highway (KKH) to become obstructed or broken. Most respondents stated that in the face of such occurrences, villagers turned to self-help. In the villages, there is no formal mechanism for coping and being prepared. They actively participate in offering rescue and relief assistance to the sufferers of their neighborhoods and even their neighboring communities in the event of any calamity. Everyone makes use of their unique experiences, expertise, and mental and physical abilities to reduce the hazards. They don't even have hospital facilities near they have to travel other nearby villages in case of emergency as shown in (figure 3.2(a,b)).

Some people move temporarily to different cities and villages, usually to their families' residences. By pooling resources, village communities aid in risk reduction. Even though most respondents wanted to migrate to safe locations, some of them stated that they were unable to relocate due to a lack of resources shown in (figure 3.3(a,b,c,d)).

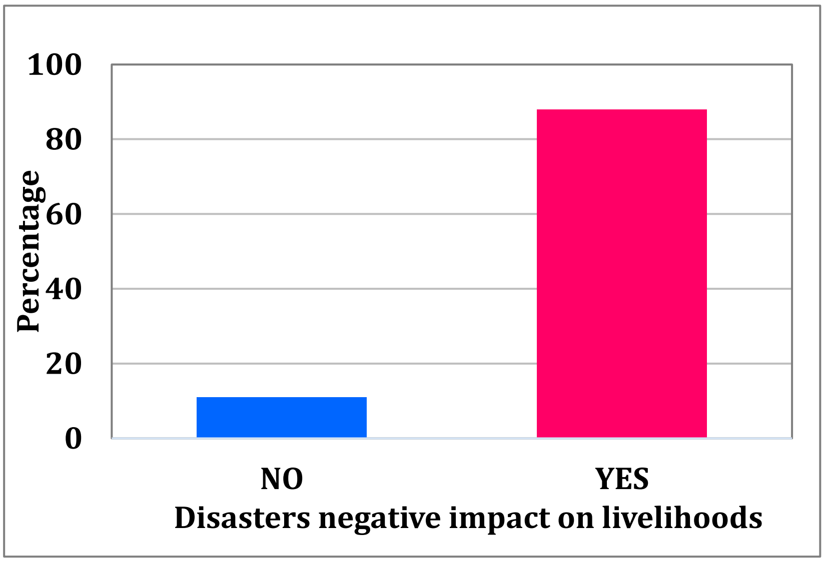

Figure 3.1. Above graph shows 85% disasters have negatively impacted the families in Ishkoman valley which were directly affected by disasters.

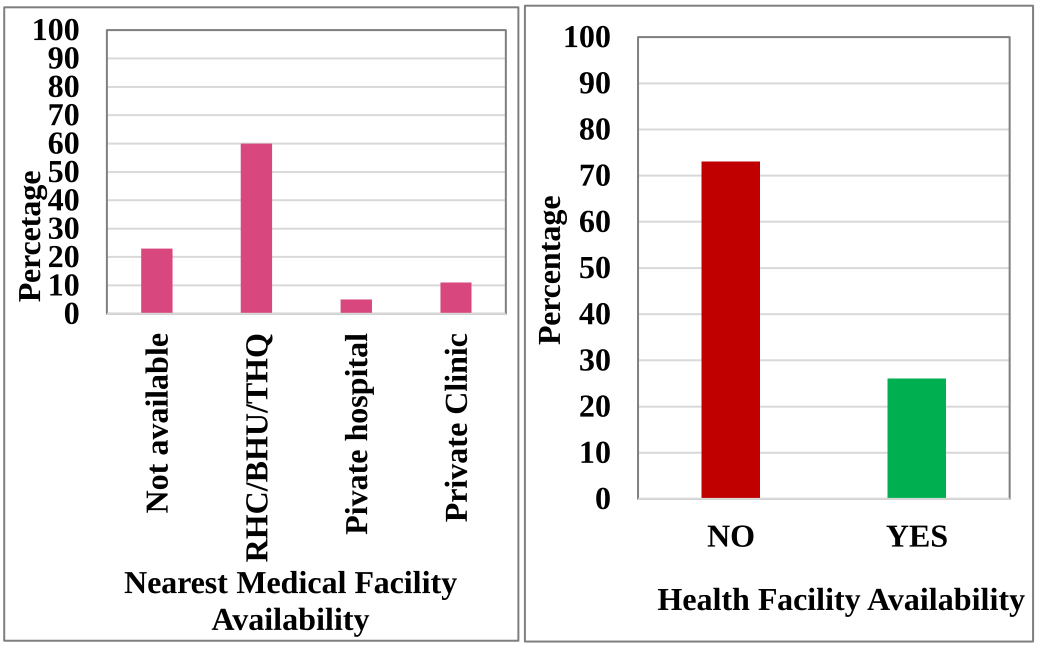

Figure 3.2(a,b). Above 3.2A graph shows that almost 80% of the population have no access to any health facilities and remaining 20% have access to but they must travel to far villages for that. 3.2B Shows 60% of Basic Health Units (BHU) are available but no Govt. hospital.

The members of the community expressed concern about the paucity of emergency medical assistance and requested prompt medical and first aid assistance. For shelter and assistance, the residents of destroyed homes were relocated to the community's religious centers and schools. Most respondents claim that in situations like these, there is no outside support from any government agency. It is now widely acknowledged that the isolation of many of the villages in the area, along with the fragile ecosystem and high altitude of the Northern Areas, present unique limits, and obstacles in mitigating natural disasters like GLOFs.

The village community used a syphoning technique to decrease the water level and drain the lake that posed a GLOF hazard to the Gilgit glacier. Efficient prevention or mitigation methods are challenging for communities to adopt because of poor livelihood conditions, an absence of resources, and poor system management as seen in (figure 3.4(a,b,c,d)). Thus, local groups are engaged in a variety of activities, but coordination and capacity expansion are lacking. Outside help is rarely available. management. Thus, local groups are engaged in a variety of activities, but coordination and capacity expansion are lacking. Outside help is rarely available.

The current research effort was conducted on three rivers—the Yasin, the Karambar, and the Gilgit River—to completely explain the model outcome. Several transects were conducted in each river to calculate the rate of bank line movement, coupled with erosion and accretion. The trend of the riverbank movement was estimated by considering all 30 years of data (1990–2020).

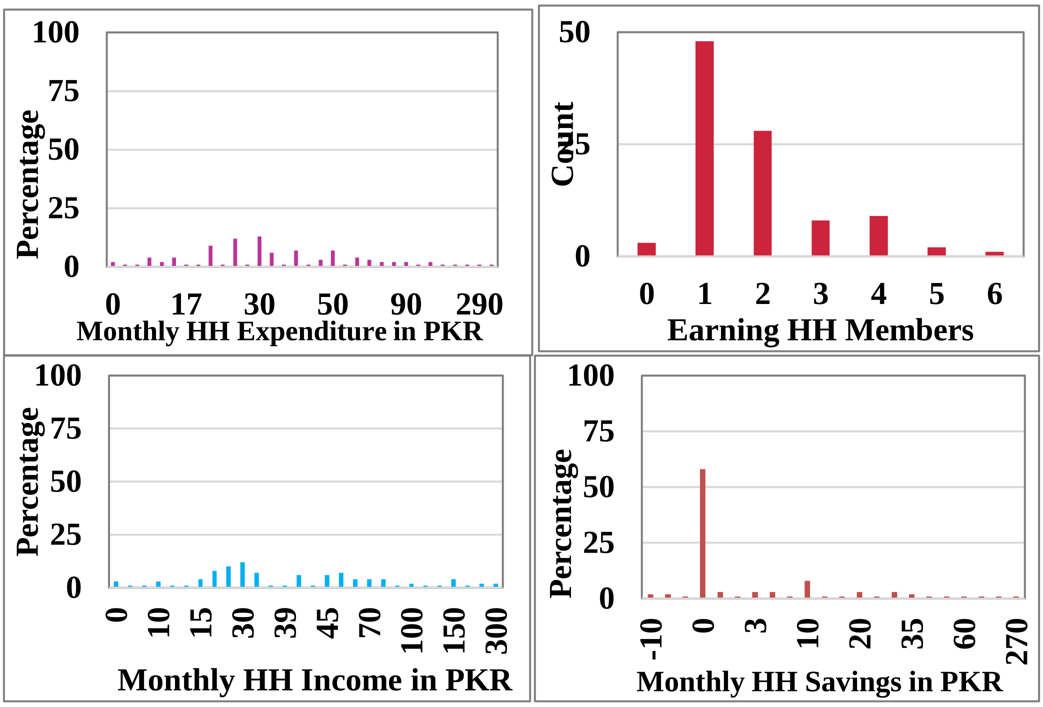

Figure 3.3(a,b,c,d). Charts show Monthly Household Income min. 6k to max 170k and expenditure 6k to 290k. About 70% of them have zero savings by the end of the Month and about 50% of houses have 1 earning member in their family.

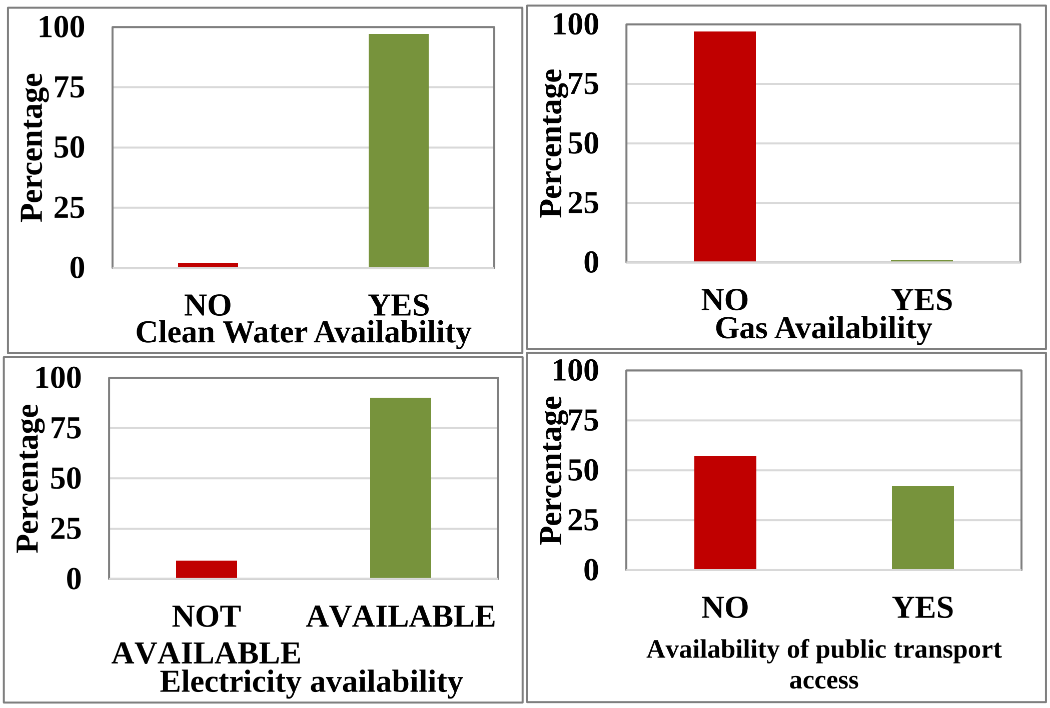

Figure 3.4(a,b,c,d). 3.4A shows about 95% have access to clean drinking water. 3.4B shows about 95% do not have Gas accessibility. 3.4C shows 95% have electricity accessibility and 3.4D shows 60% have electricity accessibility to Public Transport.

3.2. Vegetation Indices (NDVI):

Normalized Difference Vegetation Index (NDVI) is frequently used to observe changes in vegetation dynamics, its relationship to various climatic conditions, particularly temperature and precipitation, which are thought to have the greatest impact on vegetation cover. NDVI product of Landsat and Sentinel images were used from the years 1990 to 2022 to examine the changes in vegetation GEEs Data Catalog. The range of NDVI values is (-1) to (+1). A value near to +1 shows that the maximum likely of green leaves density, while a value closer to (-1) indicates no flora shown in (figure 3.5(a,b,c,d)).

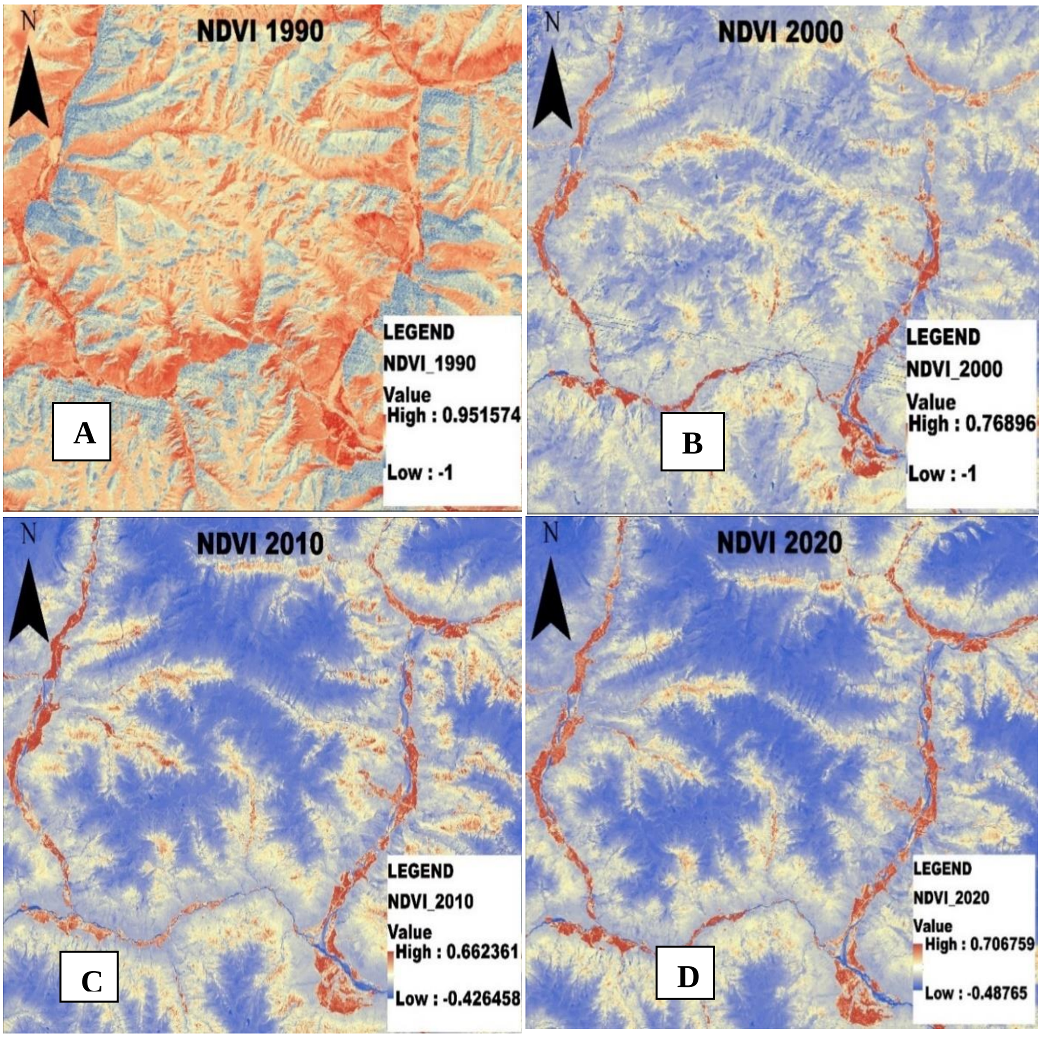

Figure 3.5(a,b,c,d). The comparative NDVI situation of Ishkoman valley for year 1990 to 2020. Given maps shows the overall change of 30 years in which the red color shows vegetation.

RED band shows the spectral reflectance in the red region and NIR band shows the spectral reflectance in the NIR near-infrared region. The spectral reflectance of Bands 4 and 5 was used for NDVI of Landsat-5 and Landsat-8. And Bands 4 and Bands 8 were used for Sentinel 2 imagery. To track changes over a 30-year period, from 1990 to 2022 researchers looked at land use and landcover changes in the Ishkoman region of the Ghizer district. The current study also tries to evaluate how the landscape has changed in the Ghizer district of Gilgit-Baltistan, Pakistan.

NDVI product of Landsat 5, Landsat 8 and Sentinel 2 for year 1990 to 2022 downloaded from Google Earth engine and then after some processing like atmospheric correction, radiometric correction and geometric corrections, the final product is being utilized data of Some of the years are missing. From year 1990 to 2020 we can clearly see the difference in vegetation cover and snow cover as the snow cover is decreasing and melting because of rise in temperature in mountainous area and vegetation cover is decreasing and we can clearly see the urban growth. This means that the landscape has changed over the last three decades and the main reason behind this is the climatic conditions or particularly temperature and precipitation patron.

In image (3.5A) the NDVI product of the year 1990 shows that that it has more vegetation and snow cover, and the vegetation is showing red color. In image 3.5B, the NDVI product of the year 2000 Please join the overall vegetation cover and as compared to year 2000 it's shown that in 10 years the vegetation cover has decreased which is shown in red color. In image 3.5C, the NDVI product of year 2010 shown that vegetation has increased and shows that this snow cover is decreasing. The reason behind this is the increase in temperature. Similarly in image 3.5D, 2022 NDVI product shows that the vegetation cover is decreased, and snow cover is also decreasing.

3.3. Vectorization of Houses and Fields

The vectorization of houses and fields was done using Google Earth pro. In the map Three Rivers Yasin, Gilgit and Karambar was extracted and used and the houses and agriculture fields around them are being digitized manually with the help of Google Earth. The green color shows the vegetation, and the red color shows the built-up area in Ghizer district.

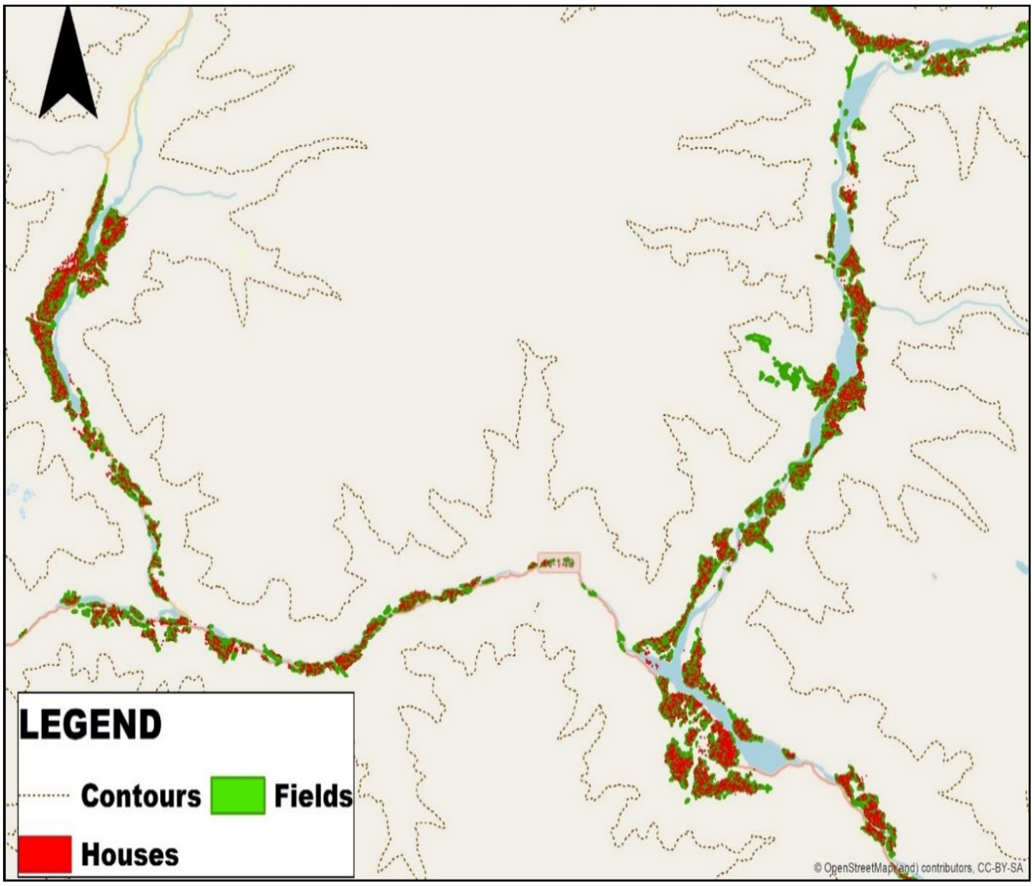

Figure 3.6**.** Vectorization of the Karambar valley was done. Karambar valley starts from Karambar lake and ends at Ghakuch at its lowest elevation. Houses and fields well manually digitized which shows the present settlements along the river.

3.4. Prediction of Bankline shifting using the DSAS model

These are the three statistical values determined by DSAS: (1) NSM (2) SCE (3) EPR. Everytransects has its data calculated, with rates expressed in meters per year. The NSM calculated separation in meters between the shorelines that are the oldest and youngest. SCE, which is independent of time, is the separation in meters between the two farthest shorelines.

By dividing NSM by the amount of time that has passed between the oldest and youngest shorelines, the EPR determines the net shoreline movement rate. Both NSM and EPR only consider the shorelines that are the oldest and youngest and ignore all other shorelines

3.5. Bankline Change

The Bankline change analysis statistics done by DSAS results in the creation of two new feature classes. A duplicate of the transect feature class with shoreline change statistics is the first new feature class. The sites where the transect lines cross the shorelines in the second have position records. Together with these feature classes, a text file with a summary report that offers the averages for all the derived statistics is also generated.

3.6. KARAMBAR RIVER

3.6.1. SCE for Karambar River

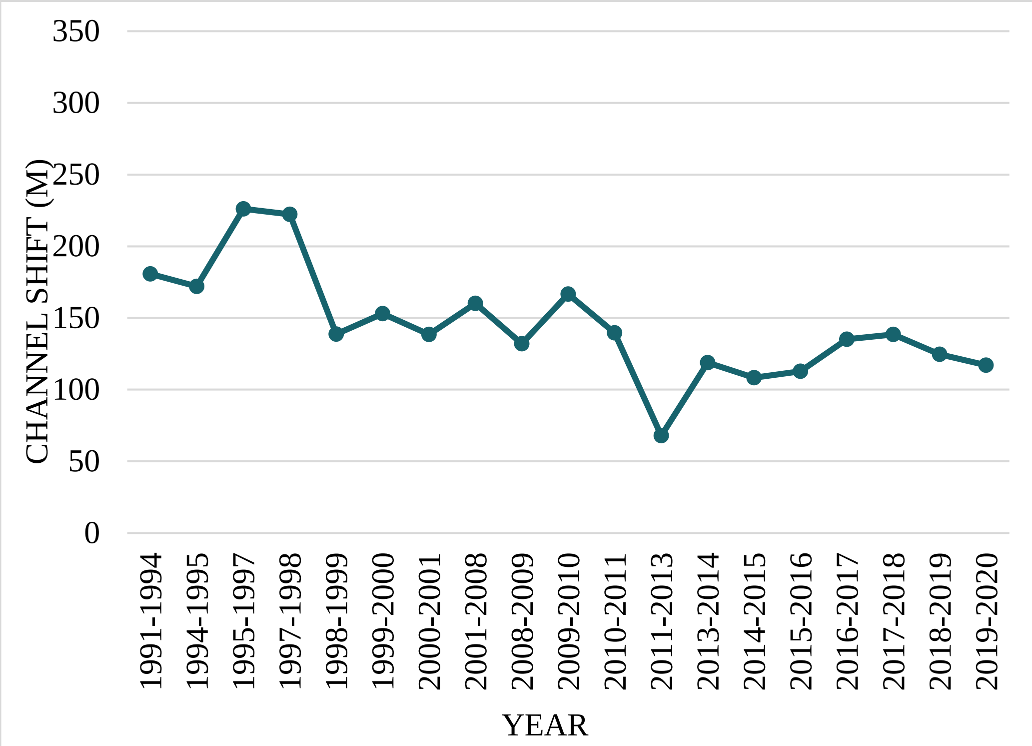

Figure 3.7. Shoreline Change Envelope shows the overall change for Karambar River for the year 1990 to 2020.

3.6.2. NSM For Karambar River

Multiple case studies on GLOF by (Iturrizaga, 2005) shows that flood events were affecting the karambar valley for past 150 years. Some of the events were covered in his research which was conducted in the years 2002-2004 in Karambar valley. Which shows that in the years 1997 and 1998 glof event occurred. According to (Hewitt, 1998) in year 1993 glof event occurred and in year 2004 golf event occurred at Chattaboi glacier (Iturrizaga, 2005). There is evidence that at least two ice-dammed lakes coexisted within the Karambar Valley at the same time. Assuming that those lakes coexisted, the runoff generated by Chattaboi lake may have caused the lower Karambar lake to erupt, starting a chain of lake eruptions.

In figure 3.9a the outcome reveals that between 1990 and 2000, the Karambar riverbank shifted at an average rate of 180.62 m/y and 152.95 m/y, respectively. Average rates of erosion and accretion were 187.0 m/yr and 177.8 m/yr and 169.0 m/yr and 132.7 m/yr, respectively. The bank encountered an average movement of 27.67 m/yr during this time. The outcome demonstrated that, at this time, more bank line erosion meant that channel expansion predominated over channel narrowing.

In figure 3.9b the average shifting rate between 2000 and 2010 was 138.44 m/yr and 166.59 m/yr, respectively. The average rates of erosion and accretion were respectively 80.6 m/yr, 170.3 m/yr, 110.0 m/yr, and 189.6 m/yr. The transects position revealed that accretion had been placed and that there had been a higher rate of moving. The overall average shifting rate at this time was 28.15 m/yr. It shows that throughout this time, erosion was more widespread on riverbanks.

In figure 3.9c the average shifting rate between 2010 and 2020 was 140.33 m/yr and 116.15 m/yr, respectively. Transect locations demonstrated that accretion had occurred and that the channel had moved closer towards the bank. According to the findings, accretion occurred at a rate of 100.4 m/yr and 123.7 m/yr, erosion occurred at a rate of 167.0 m/yr and 110.0 m/yr, respectively. And the overall average shifting rate was 24.18m/yr. It demonstrates that river erosion predominated over accretion as shown in (figure 3.8).

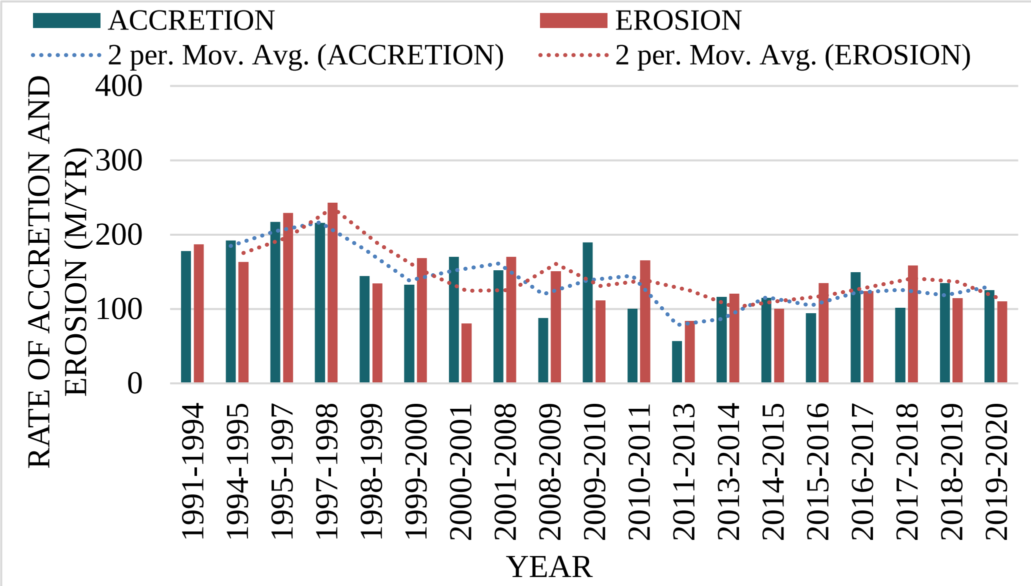

Figure 3. 8. Net shorelines movement of Karambar river shows erosion and accretion rate for the year 1990 to 2020. Overall erosion was predominant for this river.

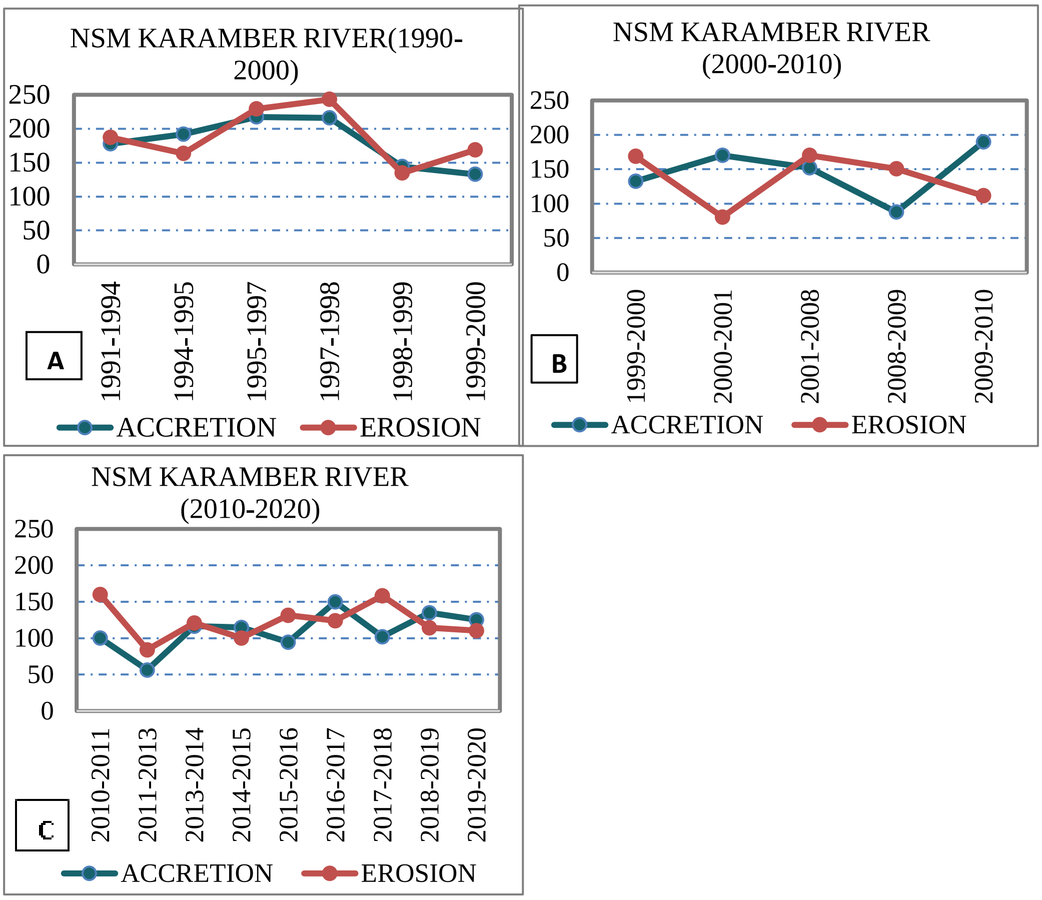

Figure 3.9(a,b,c). Above three graphs shows the net shoreline movement for Karambar River for the span of 30 years i.e. 3.9A Graph show changes for 1990 to 2000, 3.9B show changes for year 2000 to 2010 and 3.9C show changes for year 2010 to 2020.

3.6.3. EPR For Karambar River

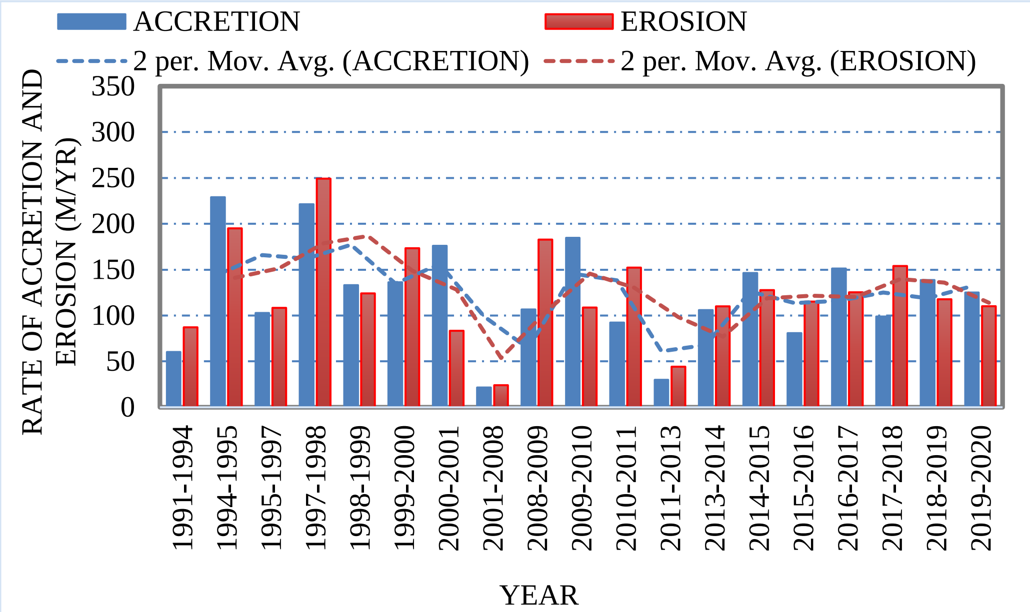

Figure 3.10. End Point Rate of Karambar river shows how fast the bank line changes between the years 1990 to 2020.

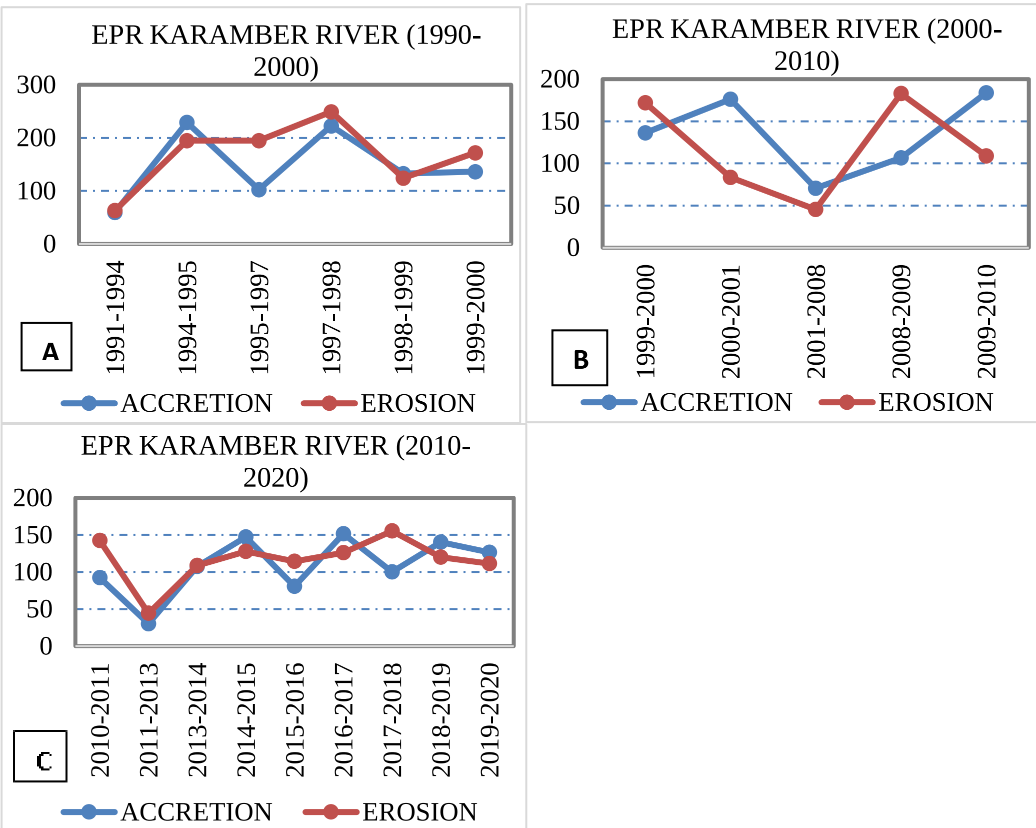

Figure 3.11(a,b,c). Above 3 graph shows endpoint rate of Karambar River i.e. 3.11A Graph show changes for 1990 to 2000, 3.11B show changes for year 2000 to 2010 and 3.11C show changes for year 2010 to 2020.

3.6.4. Overall Change in Bank Line of Karambar River

For 30 years of shoreline data, the DSAS summary report provides the average shoreline change rates as well as erosion and accretion. At an average EPR of 123.4 m/yr (accretion) and 128.80 (erosion) and average NSM between 1990 and 2020 is 140.73 m/yr (accretion) and 144.41 m/yr (erosion) as shown in (figure 3.12). There are some river segments that are eroding even though the average shoreline rate indicates that accretion is the predominant tendency.

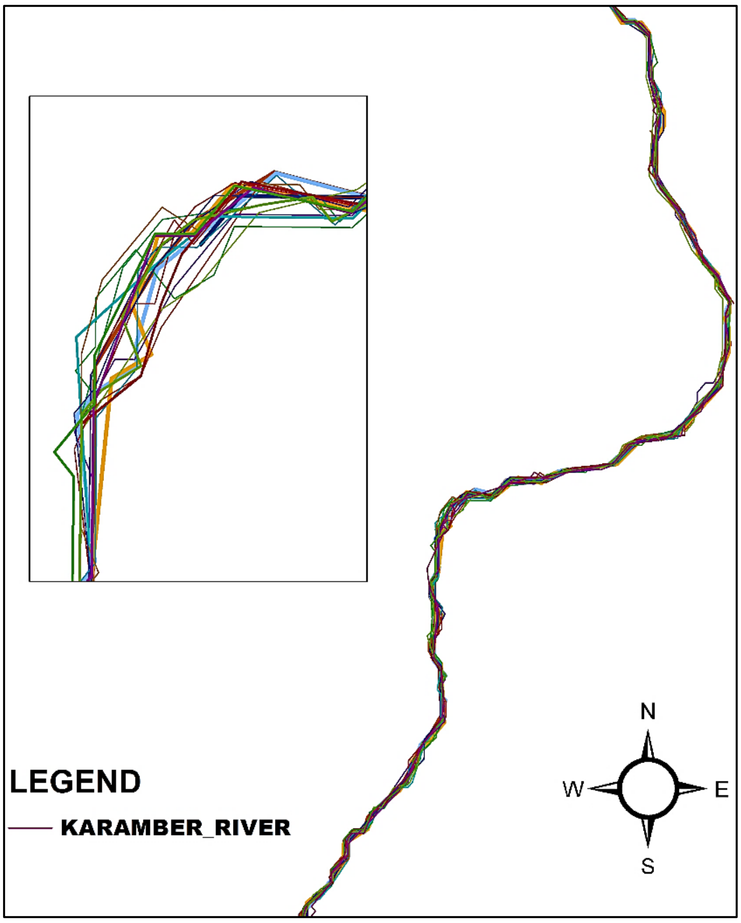

Figure 3.12**.** Map shows the overall change in Karambar river for past three decades (1990 to 2020).

3.7. GILGIT RIVER

3.7.1. SCE For Gilgit River

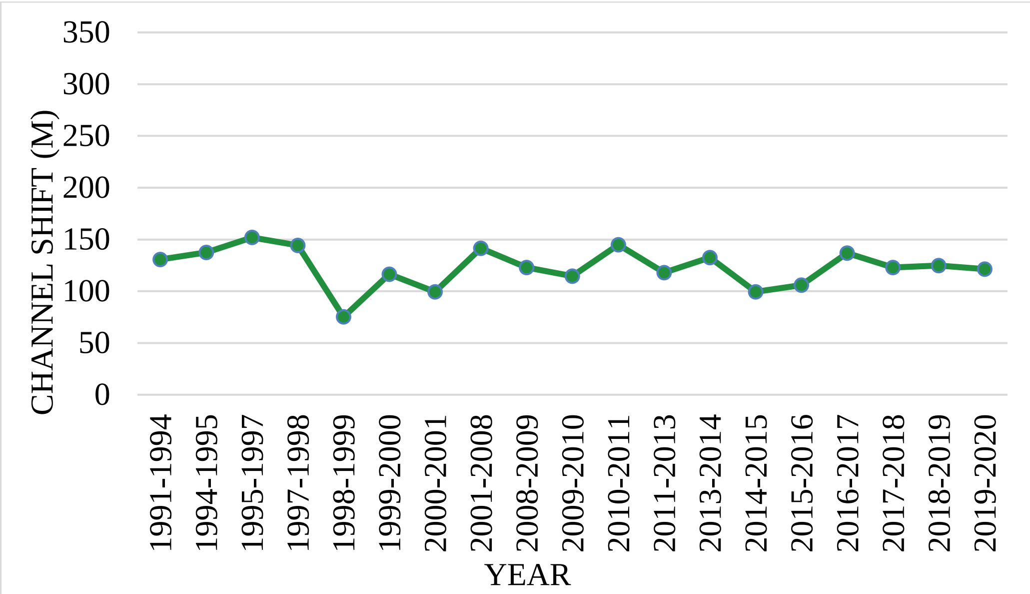

Figure 3.13. Shows the overall change for the past three decades (1990 to 2020) of Gilgit river.

3.7.2. NSM For Gilgit River

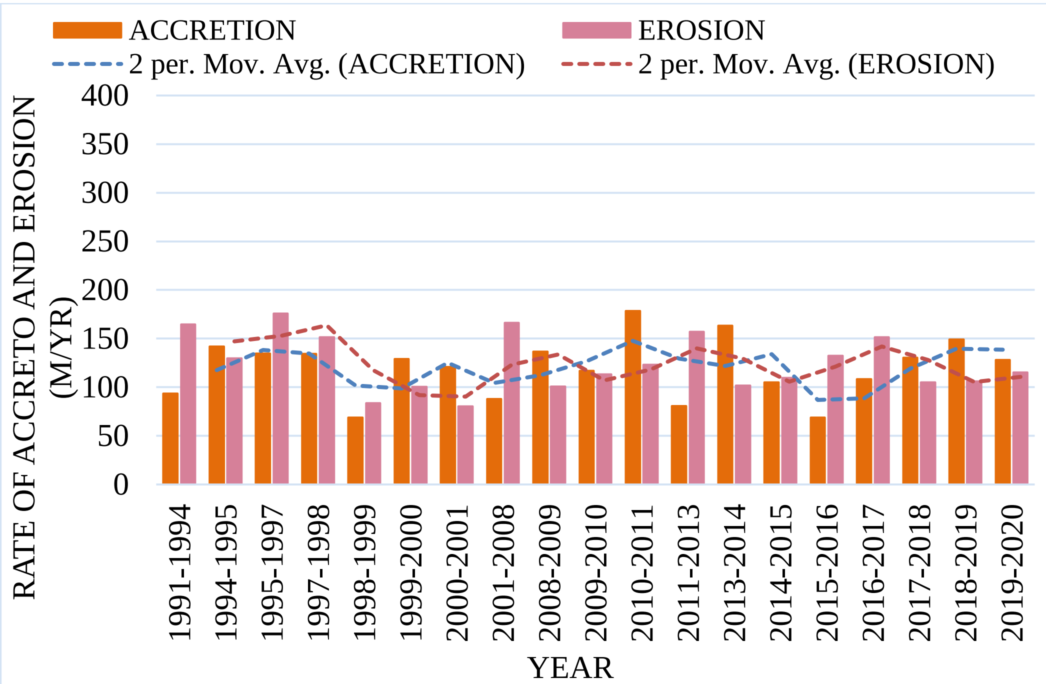

Figure 3.14. Net Shoreline Movement shows the Erosion and accretion for the past three decades (1990 to 2020) of Gilgit River. Overall erosion was predominant for Gilgit River.

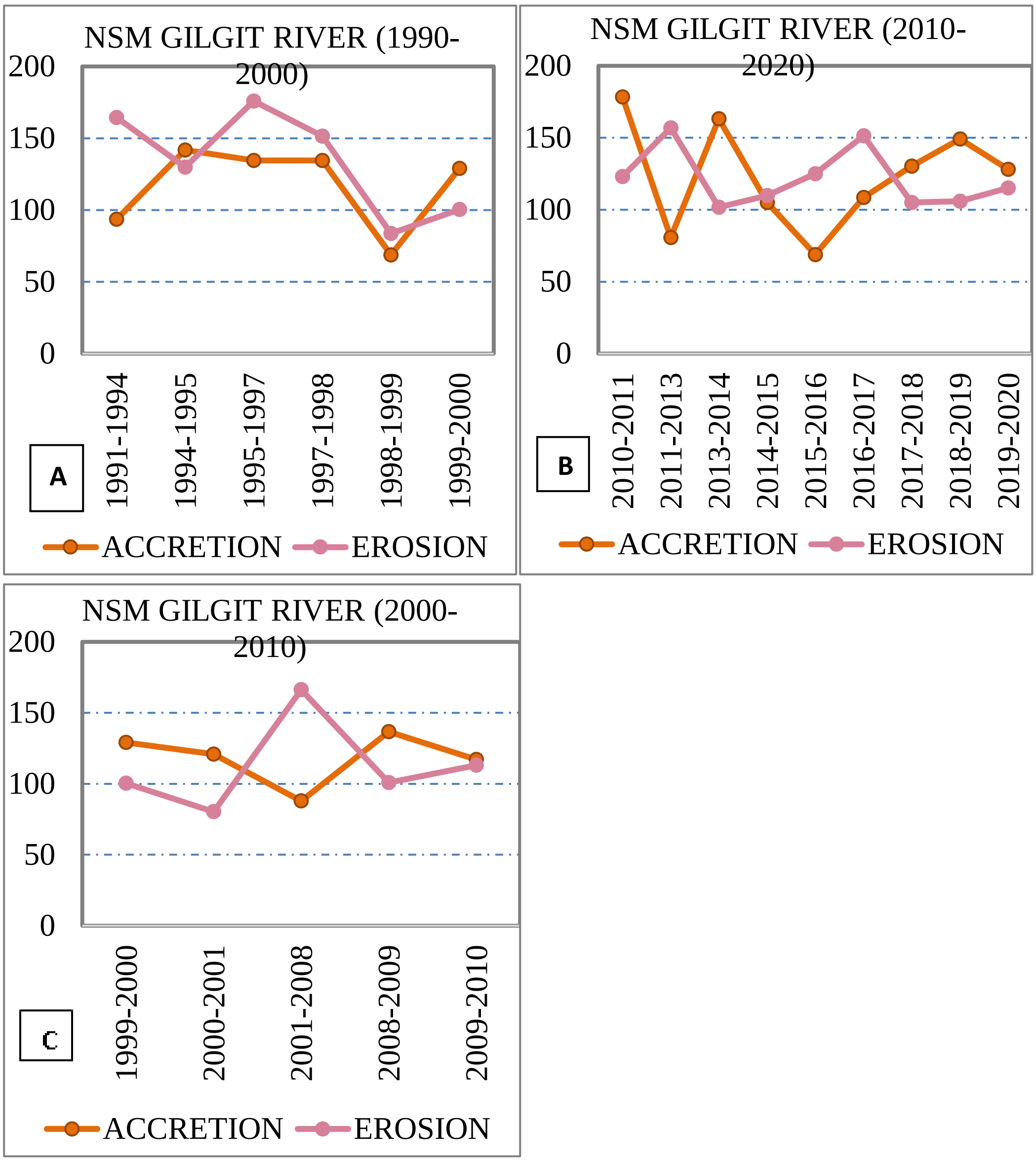

Figure 3.15(a,b,c): The above 3 graph shows net shoreline movement of Gilgit River i.e. 3.15A Graph show changes for 1990 to 2000, 3.15B show changes for year 2000 to 2010 and 3.15C show changes for year 2010 to 2020.

Between 1990 and 2000, the Gilgit riverbank shifted at an average rate of 130.65 m/yr and 116.31 m/yr, respectively. Average rates of erosion and accretion were 164.5 m/yr and 100.4 m/yr and 93.53 m/yr and 129.02 m/yr, respectively as shown in (figure 3.15a). The bank encountered an average movement of 14.34 m/yr during this time. The outcome demonstrated that, at this time, more bank line erosion meant that channel expansion predominated over channel narrowing.

The average shifting rate between 2000 and 2010 was 99.33 m/yr and 114.52 m/yr, respectively. The average rates of erosion and accretion were respectively 80.28 m/yr, 113.1 m/yr, 120.92 m/yr, and 117.05 m/yr as shown in (figure 3.15b). The transects position revealed that accretion had been placed and that there had been a higher rate of movement. The overall average shifting rate at this time was 15.19 m/yr. It shows that throughout this time, erosion was more widespread on riverbanks.

The average shifting rate between 2010 and 2020 was 144.78 m/yr and 121.42 m/yr, respectively. Transect locations demonstrated that accretion had occurred and that the channel had moved closer towards the bank. According to the findings, accretion occurred at a rate of 178.41m/yr and 128.07m/yr and erosion occurred at a rate of 123.1m/yr and 115.1m/yr, respectively as shown in (figure 3.15c). The average shift was 23.36 meters per year as shown in (figure 3.14). It demonstrates that river accretion predominated over erosion.

3.7.3. EPR For Gilgit River

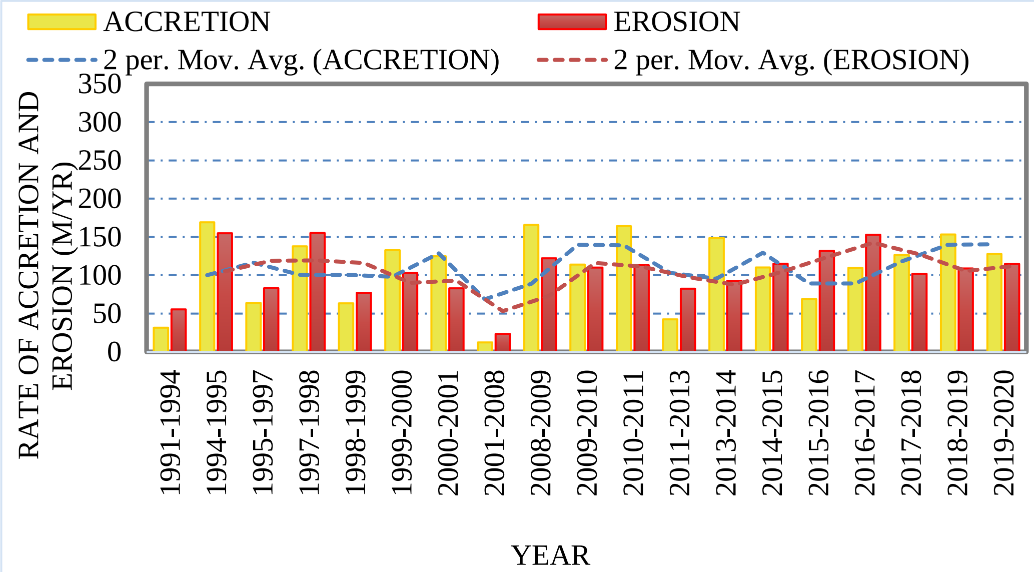

Figure 3.16. The End Point Rate of Gilgit River shows how fast the bank line changes for the year 1990 to 2020.

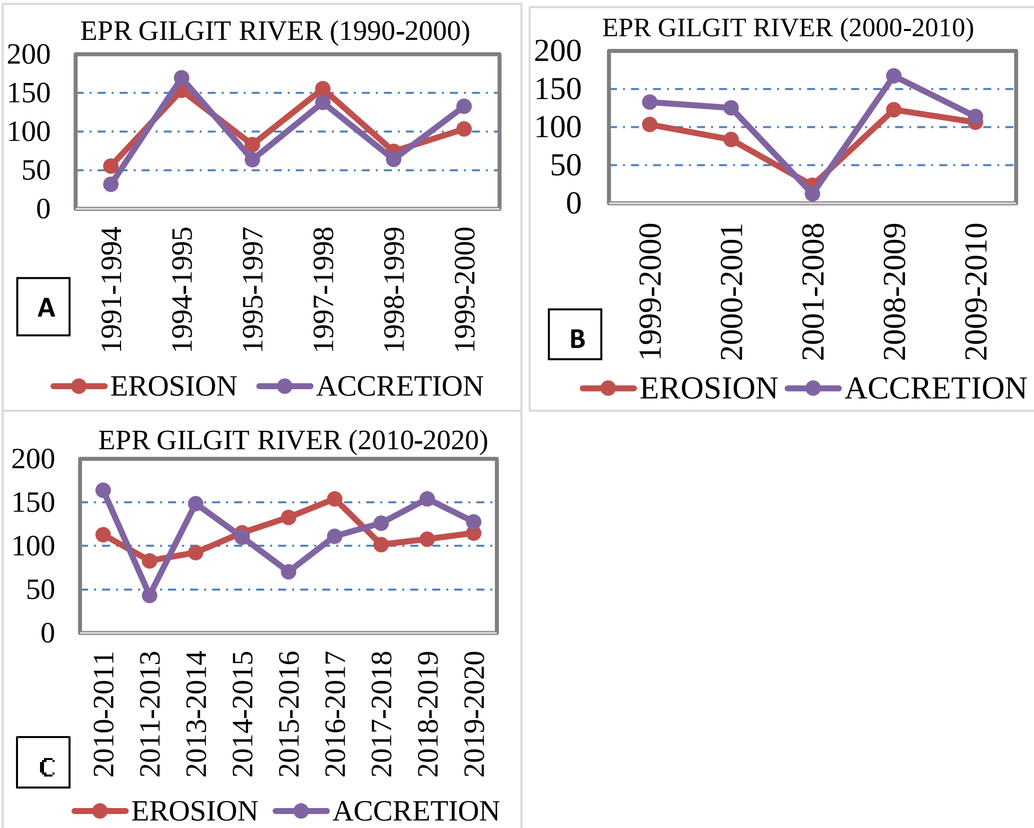

Figure 3.17(a,b,c**)**. The above 3 graph shows endpoint rate of Gilgit River i.e. 3.17A Graph show changes for 1990 to 2000, 3.17B show changes for year 2000 to 2010 and 3.17C show changes for year 2010 to 2020.

3.7.4. Overall, River Bankline Change for Gilgit River

For the shorelines, the DSAS statistics were performed from 1990 to 2020. For 30 years of shoreline data, the DSAS summary report provides the average shoreline change rates as well as erosion and accretion. In figure 3.17, an average EPR of 109.09 m/yr (accretion) and 104.03 (erosion) and average NSM between 1990 and 2020 is 118.97 m/yr (accretion) and 124.22 m/yr (erosion) There are some river segments that are eroding even though the average shoreline rate indicates that accretion is the predominant tendency.

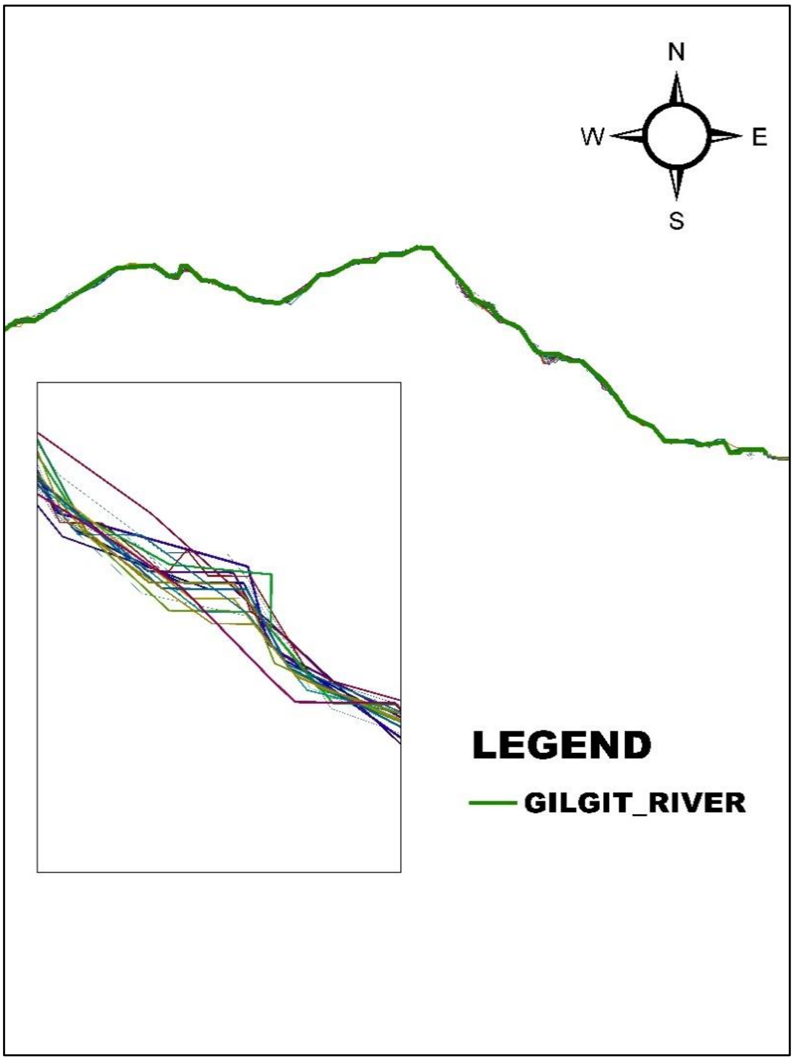

Figure 3.18. Map shows the overall change in Gilgit River for the past three decades (1990-2020).

3.8. YASIN RIVER

3.8.1. SCE For Yasin River

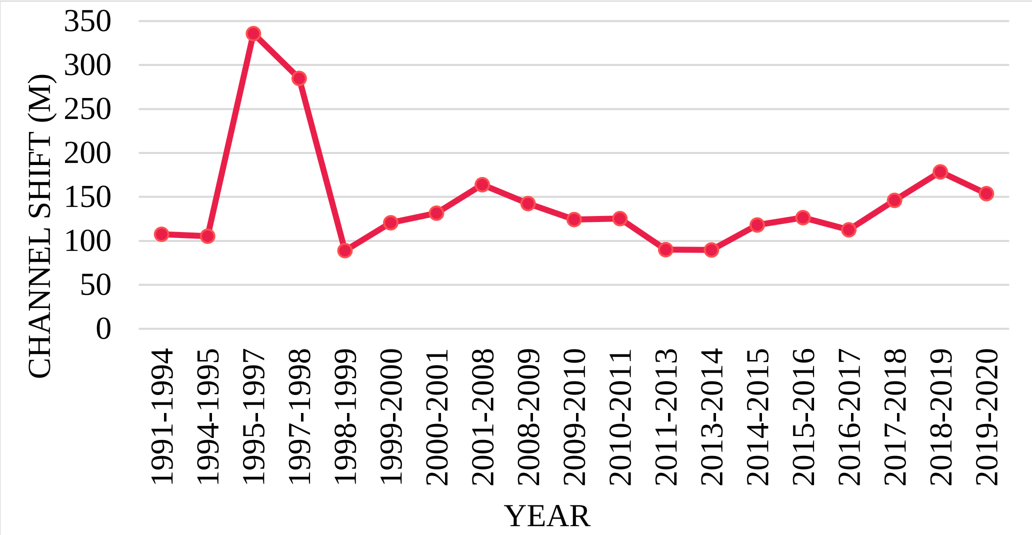

Figure 3.19. Shoreline Change Envelope shows channel shift for the year 1990 to 2020. It Shows that year 1997 has the highest shift and according to previous research a GLOF event have occurred which results in the highest riverbank shift in that year.

3.8.2. NSM For Yasin River

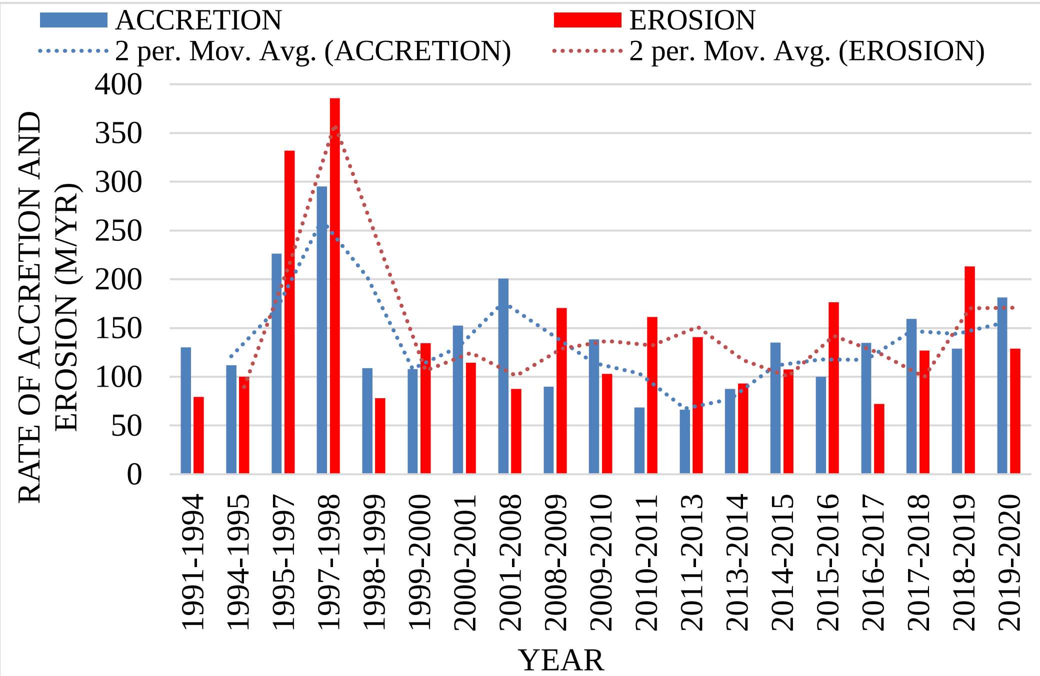

Figure 3.20. NSM shows the longest erosion and accretion change for the year 1990 to 2020. Overall erosion was predominant for Yasin River and in year 1997 it shows the highest erosion

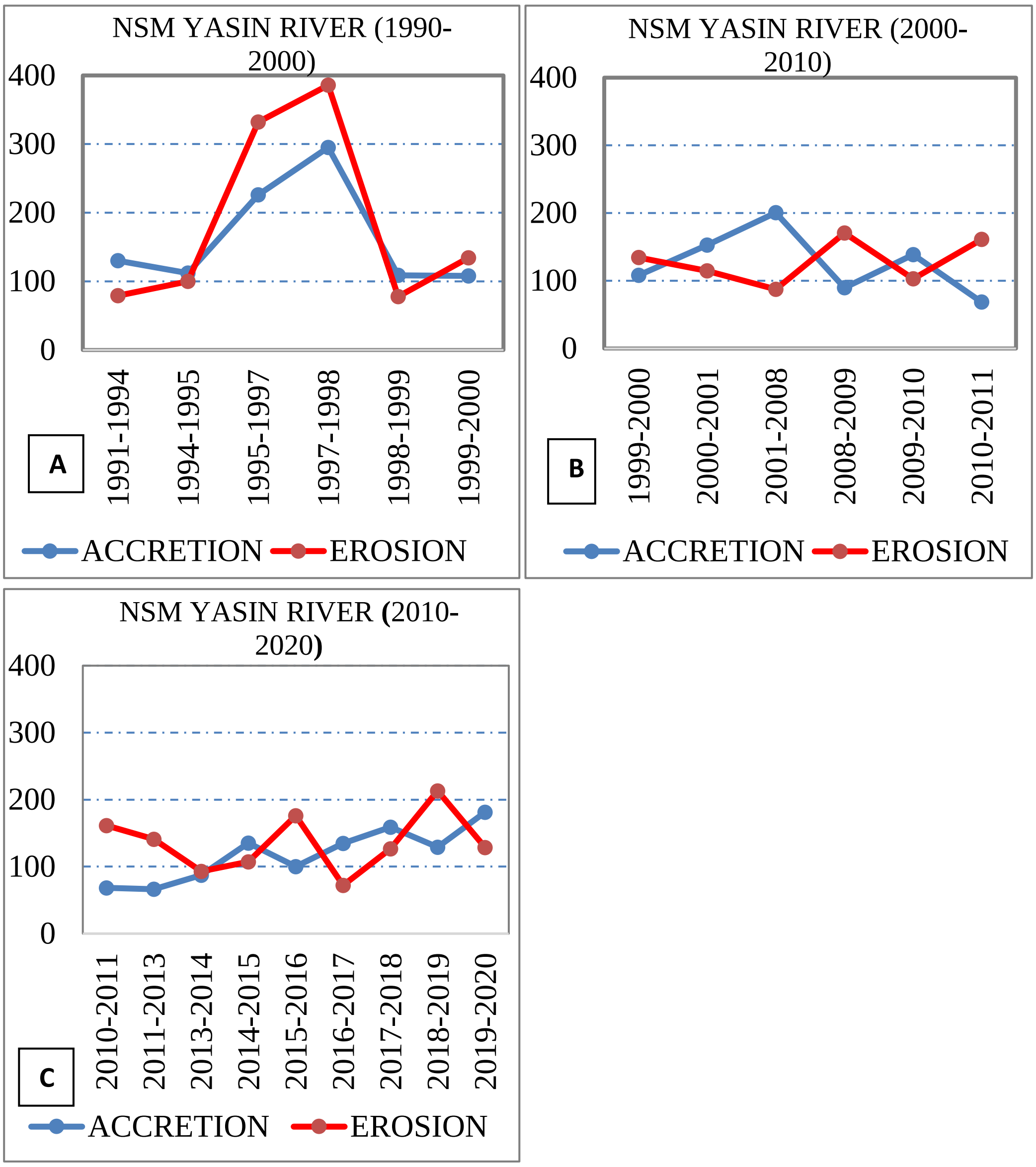

Figure 3.21(a,b,c): The above 3 graph shows Net Shoreline Movement in Yasin River i.e. 3.21A Graph show changes for 1990 to 2000, 3.21B show changes for year 2000 to 2010 and 3.21C show changes for year 2010 to 2020

Between 1990 and 2000, the Yasin riverbank shifted at an average rate of 107.52 m/yr and 120.66 m/yr, respectively. Average rates of erosion and accretion were 79.19 m/yr and 135.35 m/yr and 129.99 m/yr and 107.95 m/yr, respectively as shown in (figure 3.21a). The bank encountered an average movement of 39.16 m/yr during this time. The outcome demonstrated that, at this time, more bank line erosion meant that channel expansion predominated over channel narrowing.

The average shifting rate between 2000 and 2010 was 131.57 m/yr and 124.18 m/yr, respectively. The average rates of erosion and accretion were respectively 114.5 m/yr, 102.9 m/yr, 152.4 m/yr, and 138.3 m/yr as shown in (figure 3.21b). The transects' position revealed that accretion had been placed and that there had been a higher rate of moving. The overall average shifting rate at this time was 12.85 m/yr. It shows that throughout this time, sedimentation rather than erosion was more widespread on riverbanks.

The average shifting rate between 2010 and 2020 was 125.34 m/yr and 153.82 m/yr, respectively as shown in (figure 3.21c). Transect locations demonstrated that accretion had occurred and that the channel had moved closer towards the bank. In figure 3.20 According to the findings, accretion occurred at a rate of 68.44 m/yr and erosion occurred at a rate of 161.23 m/yr and 128.76 m/yr, respectively. It demonstrates that river accretion predominated over erosion.

3.8.3. EPR For Yasin River

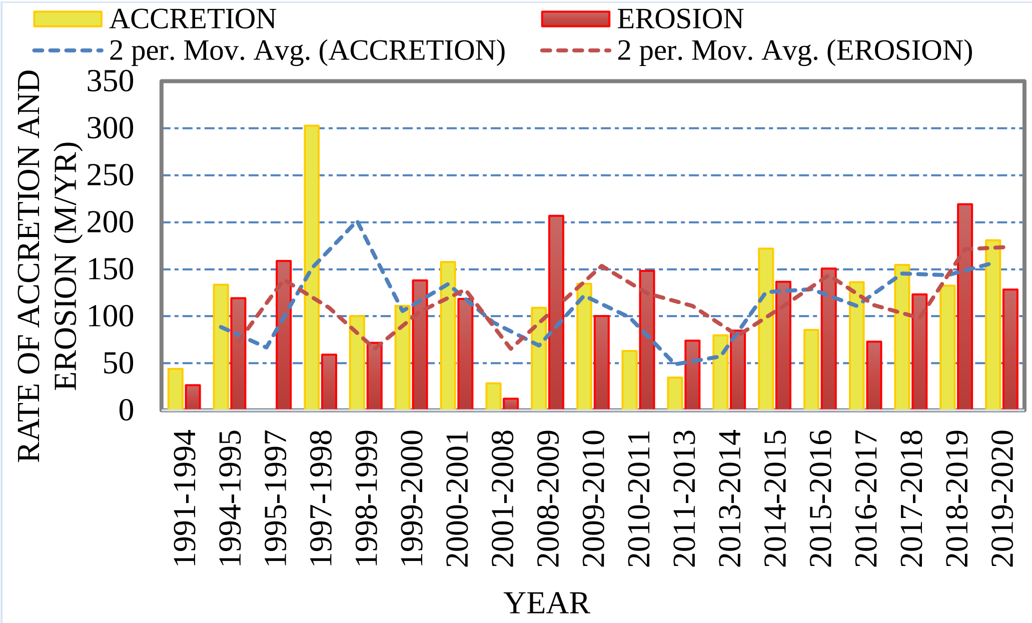

Figure 3.22. Endpoint Rate shows how fast the bank line changed and for the year 1997 it shows the highest change in bank line.

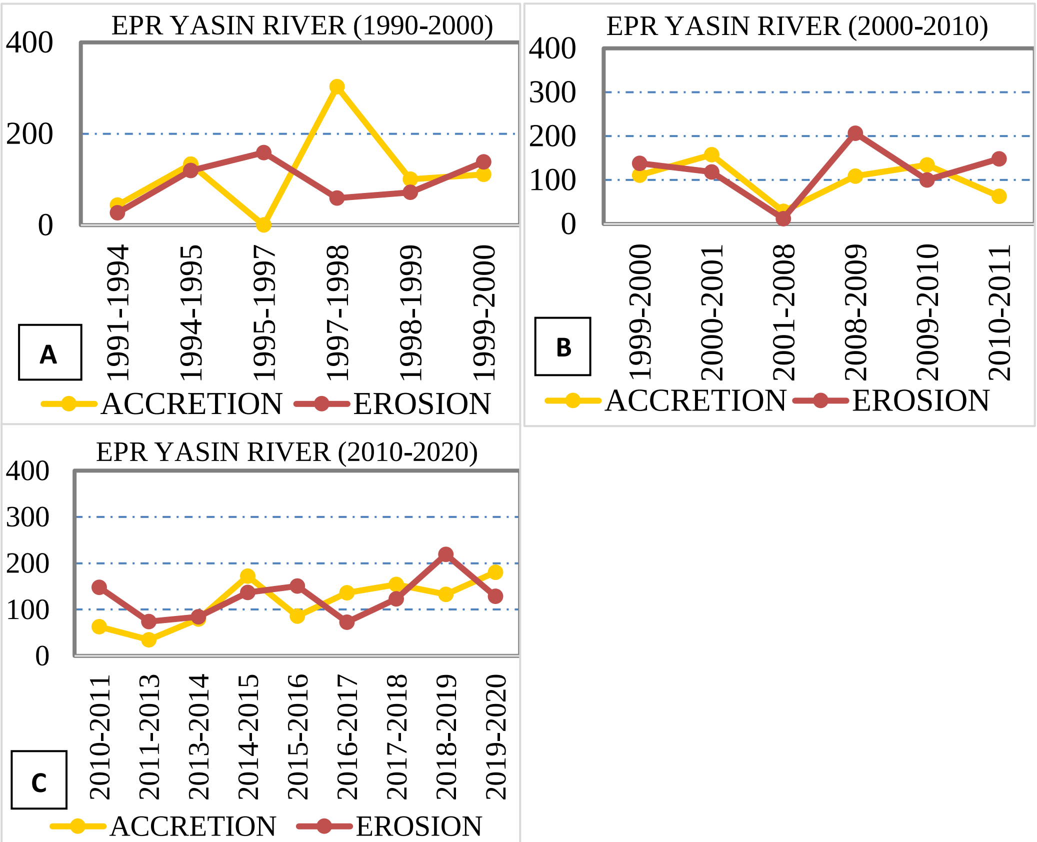

Figure 3.23(a,b,c). The above 3 graph shows endpoint rate in Yasin River i.e. 3.23A Graph show changes for 1990 to 2000, 3.23B show changes for year 2000 to 2010 and 3.23C show changes for year 2010 to 2020

3.8.4. Overall River Bankline Change for Yasin River

For the shorelines, the DSAS statistics were performed from 1990 to 2020. For 30 years of shoreline data, the DSAS summary report provides the average shoreline change rates as well as erosion and accretion. At an average EPR of 120.00 m/yr (accretion) and 113.05 m/yr (erosion), the average NSM between 1990 and 2020 is 138.05 meter (accretion) and 152.76 meter (erosion). In figure 3.23, there are some river segments that are eroding even though the average shoreline rate indicates that accretion is the predominant tendency.

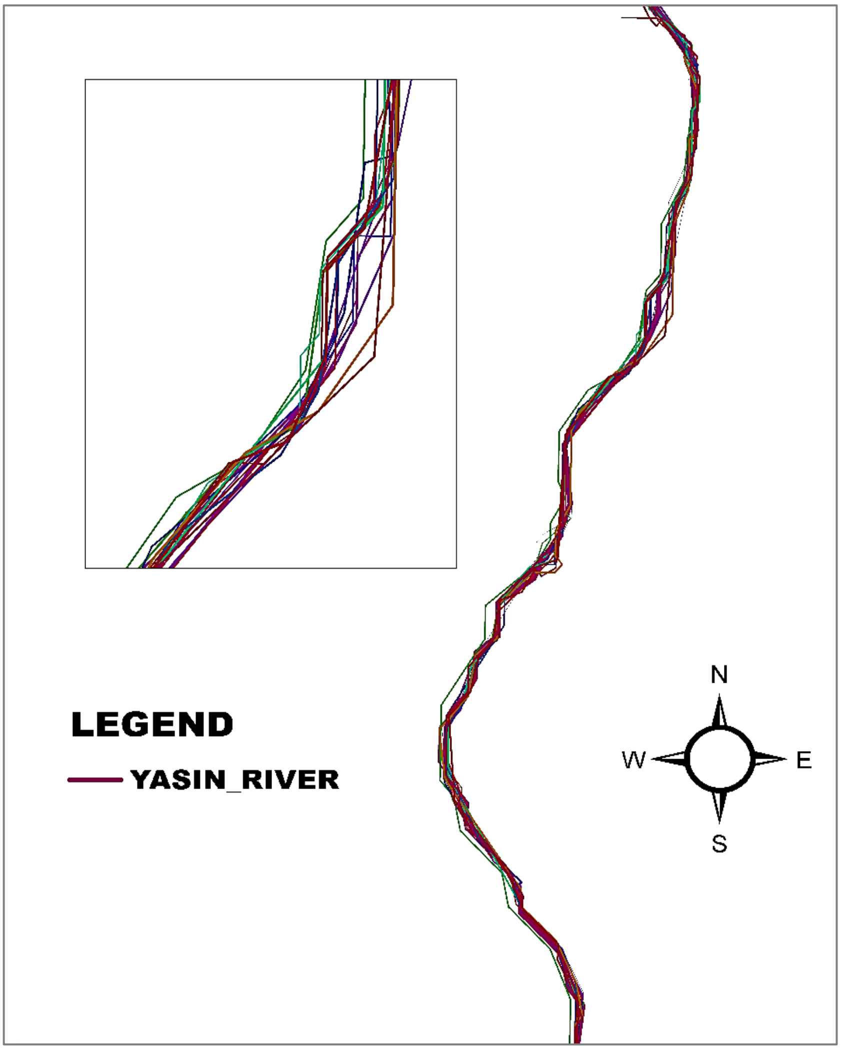

Figure 3.24. Map shows the overall change in Yasin River for the past three decades (1990-2020).

This study discovered that erosion was predominant for karambar, Gilgit and Yasin River. This Short-term shoreline change analysis can be utilized to better understand shoreline variability and identify seasonal variations.

3.9. DISCUSSION

Riverine channel morphology is evolving due to contemporary human activity and climate change, (Boota et al., 2021). The channel structure and pattern will be disturbed by a breakdown of dynamic equilibrium caused by a change in river geometry (Petts & Gurnell, 2005). As a result, such activities not only worsen the hydro-geomorphology, erosion of the banks, and banks failure of the river (Yang et al., 2015) but they also have a negative impact on the environment and biodiversity (Jain, 2012). In (Vaidya et al., 2019) Book he discussed a component of the Third Pole, the Hindu Kush Himalayan are one of the most dangerous places on earth because of the glacier surges, GLOF events, seismic activities, landslides, avalanches, severe droughts, and flash flooding. Its steep terrain, unstable geological structures, intense precipitation, and large amounts of snow and ice are the reasons for this.

The north glaciated area lacks a structured system for coping with and preparing for natural disasters, making it especially vulnerable to them. Specialized education and capacity building on risk management and hazard mitigation are required to address this. Risk assessment and mitigation are the primary natural hazards, with flash floods, river erosion, and landslides being interconnected. Rainfall does not pose a significant threat, but it does create a risk of mass movement or landslides. Villagers respond to disasters by providing evacuation and relief services, using their own experiences, knowledge, and physical and mental abilities, and temporarily relocate to other towns and villages.

The most important details in this text are the isolation of many villages in the area, the fragility of the ecosystem, and the high altitude of the Northern Areas, this makes it challenging for localities to put into place effective risk mitigation or reduction measures. The degree of physical vulnerability is noticeably rising with time. Newly built houses and other different kinds of infrastructure were constructed under unfavorable circumstances because of the population growth. Such a poorly designed developmental intervention could have disastrous effects. On the other hand, as local reaction teams are built and outside funding for recovery is made available, the ability to deal with the crisis is gradually improving (S.K. Ali Shah et al, 2019). The research effort was conducted on three rivers to calculate the rate of bank line movement, coupled with erosion and accretion, and the trend of the riverbank movement was estimated by considering all 30 years of data (1990–2020). The accretion and erosion of land were discovered using a time-series of Landsat imagery.

Multiple case studies on GLOF by (Darwin, 1895; Iturrizaga, 2005; Hewitt, 2005 ; A. N. Khan & Khan, 2015; The & Society, 2016; Bano et al., 2020; Anwar & Barcha, 2020; I. Khan et al., 2023) shows that flood events were affecting the karambar valley for past 150 years. Some of the events were covered in his research which was conducted in the years 2002-2004 in Karambar valley. Which shows that in the years 1997 and 1998 glof event occurred. According to (Hewitt, 1998) in year 1993 glof event occurred and in year 2004 golf event occurred at Chattaboi glacier (Iturrizaga, 2005). There is evidence that at least two ice-dammed lakes coexisted within the Karambar Valley at the same time. If those lakes coexisted, the runoff generated by Chattaboi lake may have caused the lower Karambar lake to erupt, starting a chain of lake eruptions. The massive impact of the 1905 flood event on the habitation regions, which exceeded that of preceding Karakoram glacial floods, would be explained by this multiple lake outburst.

For 30 years of shoreline data, the DSAS summary report provides the average shoreline change rates as well as erosion and accretion. At an average EPR of 123.4 m/yr (accretion) and 128.80 (erosion) and average NSM between 1990 and 2020 is 140.73 m/yr (accretion) and 144.41 m/yr (erosion) There are some river segments that are eroding even though the average shoreline rate indicates that accretion is the predominant tendency. Gilgit river shows an average EPR of 109.09 m/yr (accretion) and 104.03 (erosion) and average NSM between 1990 and 2020 is 118.97 m/yr (accretion) and 124.22 m/yr (erosion) There are some river segments that are eroding even though the average shoreline rate indicates that accretion is the predominant tendency. For Yasin River an average EPR of 120.00 m/yr (accretion) and 113.05 m/yr (erosion), the average

NSM between 1990 and 2020 is 138.05 meter (accretion) and 152.76 meter (erosion). Which depicts that accretion is the predominant tendency.

This study demonstrates how future investigations employing comparable short-term river channel change analyses can assist by giving the required data. Analyses of shoreline change can concentrate on past occurrences that are comparable to the present or the future. This can then be applied to enhance emergency situational policy. This will enable better decision-making and safer mitigation measures by assessing the entire shoreline throughout various time periods. This study discovered that short-term shoreline change analysis can be utilized to better understand shoreline variability and identify seasonal variations.

Chapter 4

CONCLUSTION AND RECOMMENDATIONS

4.1 CONCLUSIONS

Climate change or even atmospheric warming is not refuted by the Karakoram expansions. The first seems to be the only explanation for the observed changes in the glacier. Other aspects of the anomaly may be explained by warmer temperatures and increased moisture transport to higher altitudes. Central Karakoram is the largest of the very few places where glaciers are growing right now. This is probably because of the high elevations, the relief, and the different climates there.

Even though "disappearing" glaciers are the main prediction for ongoing climate change, the events in the Karakoram may seem like good news. After all, the main flows of the Indus and Yarkand rivers are dominated by Karakoram glacial meltwater. Around 200 million people in the drylands nearby depend on them as resources and threats. Unfortunately, the thirsty lands downstream will not benefit immediately. According to (Viviroli et al., 2011 ; Forsythe et al., 2012), Any new ice is being preserved for the long term, according to the current drop in flow of rivers from the upper Karakoram basins over the previous 20 years. Larger glaciers, on the other hand, were associated with higher hazards from glaciers during the nineteenth and early twentieth centuries. (Hewitt, 1998). If the expansions of today primarily reflect redistribution of ice downslope, climatic warming may eventually accelerate depletion. The greatest issue in this regard is the relative neglect of this one-of-a-kind high mountain glacial region and the absence of a established systems for monitoring climatic changes and other development in the glaciers zone.

According to the study, communities understand the potentially fatal consequences of GLOF, that can be leveraged to increase their resilience to them through dissemination of risks, preparedness advertisements, and measures to adapt to climate change. To identify locations with a greater or lesser propensity for erosion and accretion processes, the study's rivers variability evaluation, which is a qualitative value, was accomplished, an actual technique for assessing changes in river morphology. The investigation of the variations of the Karambar, Yasin, and Gilgit Rivers for the period of 1990 to 2020 using satellite images and DSAS application was an accurate and efficient methodology for both saving survey time and providing quick and comprehensive results.

Conversely According to the study, Yasin River, Karambar river and Gilgit river experienced both erosion and accretion. Using EPR statistics, the long-term mean erosion rate for Karambar river is 123.4 m/yr (accretion) and 128.80 (erosion) and average NSM between 1990 and 2020 is 140.73 m/yr (accretion) and 144.41 m/yr (erosion). For Gilgit river shows an average EPR of 109.09 m/yr (accretion) and 104.03 (erosion) and average NSM between 1990 and 2020 is 118.97 m/yr (accretion) and 124.22 m/yr (erosion). And for Yasin River an average EPR of 120.00 m/yr (accretion) and 113.05 m/yr (erosion), the average NSM between 1990 and 2020 is 138.05 meter (accretion) and 152.76 meter (erosion). NSM measures the shoreline segment that shifted the most landward.

In addition to computing the erosion and accretion patterns of the mountainous terrain, the DSAS application includes exceptional and scientific features for secondary indicators. The examination of shoreline change may serve as a backdrop for subsequent research into causes and workable solutions.

4.2 RECOMMENDATIONS FOR FURTHER RESEARCH

As the smallest glacier dam in terms of height, the Chattaboi glacier dam is prone to spillover runoff. This may have also been the cause of the glacial lake outburst within the Karambar Valley (4250 m), which began in June relatively early in the year. Due to erroneous assumptions and a lack of understanding about their future, the Karakoram glaciers are in danger. the importance of considering mountain habitats and peoples while evaluating glaciers and reacting to changes that influence them.

There are several different types of natural ice and sediment barriers in the Karambar valley. The previous glacier dams' reconstructions showed a notable

glacier advance at the start of the 20th century. A sizable lake might form because of slight changes to the subglacial environment and glacier interior. Given that settlement areas have migrated into flood basins in recent decades, a future flood event might have catastrophic effects on the human infrastructure.
Hazards and vulnerability are significantly affected by climate change, with an increased chance of slope-dependent processes and lake formation.

The physical vulnerability and capacity to handle disasters make this dilemma significant in the context of the region being researched. To completely examine the problem, some of the suggestions are given below.

- The community nearby cultivated wheat crop during the season that was flooded because of GLOF events in Ishkoman region, thus action should be taken to control Lake's drainage in Ishkoman Valley.
- Technical teams must arrive in the valley right away to analyze the causes of the GLOF occurrence, including whether a surface or subterranean lake occurred at the triggering location or not.
- The valley should have an urgent early warning system implemented to forecast and predict any upcoming events.
- The team who responds to emergencies for the community needs to be well-trained and knowledgeable about the various natural disasters in their region.
- Sessions on natural disaster preparedness should be held in the villages.

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