

Beyond the Melt: Investigating the Frequency and Socio-Economic Impact of Glacial Lake Outburst Floods (GLOFs) in Downstream Communities OF Gilgit Baltistan and Chitral

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Abstract

Glacial Lake Outburst Floods (GLOFs) are an increasing hydro-meteorological hazard in the high-altitude areas of northern Pakistan, which is enhanced due to the increased glacial melt under human-induced climate change. This paper examines the spatial-temporal occurrence of GLOFs and assesses the socio-economic impact of GLOFs on down-stream communities in Gilgit-Baltistan (GB) and Chitral District, in the Hindu Kush-Karakoram ranges. The study is based on multi-temporal satellite imagery (Landsat and Sentinel series), historical inventory of the Pakistan Meteorological Department (PMD) and International Centre for Integrated Mountains Development (ICIMOD) highly-resolution digital elevation models, and field-based measurements in 12 high-risk valleys, showing a striking 38% increase in GLOF events over the 35-year period, with intense acceleration since Out of 3,044 glacial lakes identified over GB and neighboring Khyber Pakhtunkhwa, 33 are considered to be potentially dangerous, exposing over 7 million people to increased risk. Socio-economic effects were measured using 450 household surveys, semi-structured interviews with 85 key informants, and a geospatial combination of flood inundation maps and census, agricultural and infrastructure data. Notable disasters, such as the Gupis GLOF in Ghizer in August 2025 (destroying more than 300 houses, the Ghizer River, and displacing hundreds), demonstrate an average direct loss of USD 45 million per major outburst, mainly by destroying irrigated agricultural land (42%), road and bridge networks (31%), hydropower and irrigation systems (18% The indirect impacts (livelihood disruption, temporary migration, food insecurity, and increased poverty) lasted 4-8 years after the event, and they were disproportionately on agrarian households, women and indigenous populations with a low adaptive capacity. Vulnerability mapping identifies hotspots that are a combination of physical exposure and socio-economic marginalization. This analysis places GLOF risk as a deep-rooted socio-economic amplifier in GB and Chitral by moving beyond glaciological drivers to pre-empt human dimensions. Results highlight the necessity of combined, community-based adaptation plans, such as more effective early-warning systems, nature-based response, and transboundary risk-financing framework, to achieve resilience in current cryospheric change.

Key words: Glacial Lake Outburst Floods (GLOFs), Socio-Economic Effects; Gilgit-Baltistan; Chitral; cryospheric change; climate change adaptation; downstream vulnerability; early warning Systems; Indigenous Knowledge; Hindu Kush-Karakoram Himalaya; Pakistan; Mountain Hazards

Introduction

The Hindu Kush-Karakoram-Himalaya (HKH) region, also known as the Third Pole, is where the greatest amount of glaciers and glacial lakes in the world are concentrated, and which is the principal water tower of the Indus River Basin and supports the livelihoods of millions of people in Pakistan. This cryospheric reservoir has been experiencing unprecedented transformation in Gilgit-Baltistan (GB) and Chitral District in the Khyber Pakhtunkhwa (KP) as a result of anthropogenic climate warming. The increase in temperature, which has been recorded to be 1.5-2C above global averages in high-altitude areas since the mid 20th century, has caused snow melting, resulting in the occurrence and growth of supraglacial and moraine-dammed lakes. These lakes are naturally unstable with loose dams of moraine, a serious threat of Glacial Lake Outburst Floods (GLOFs), unexpected and catastrophic discharges of water and debris, which race down the stream with destructive power. This introduction contextualizes GLOFs in the context of overall climate-induced cryospheric change in GB and Chitral, explores the patterns of frequency of GLOFs historically, outlines the socio-economic vulnerability of downstream population, summarizes the existing literature, and proposes gaps, as well as, the purpose and importance of the current research.

The HKH cryosphere has been significantly changed by climate change. The Karakoram and Hindu Kush ranges of glaciers, though characterized by a heterogeneous response (some stable or growing owing to the precipitation pattern in the area), have been mainly receding since the 1990s. Inventories of glacial lakes based on satellite findings show that the total amount of the lakes in northern Pakistan has grown by about 26 percent between 2001 and 2013 and the area of the lakes has grown by 7 percent. By 2013, more than 3,044 lakes were discovered in GB and Chitral alone, with concentrations at an elevation of 2,500-5,500 m. This growth occurs most in the lower-to-mid altitude regions (91% growth in 2,500-3,500 m areas), where warming increases the speeds of melting and disrupts the stability of ice dams. The future lake projections indicate that the lake will keep growing until 2050 under the RCP 4.5 and 8.5 scenarios increasing the risk of an outburst. GLOFs are the resultant releases of millions of cubic meters of water in minutes of these lakes breaking because of induced or triggered events like rapid snowmelt, heavy precipitation, avalanches, or seismic activity. Peak discharges may be in excess of 10,000 m³/s, producing debris-laden floods reaching tens of kilometers in length, sweeping away valleys and filling floodplains. At least 35 destructive GLOFs have been recorded in GB and Chitral in the last 200 years, with the frequency increasing since the 1990s. Events that occurred in the 19th and early 20th centuries were little recorded, but inventories of post-1950 events are more common. Notable ones are the 1994 and 2005 Ghizer District (Sosot/Gupis) events, the 1999 Khalti Lake eruption, the 2007- 2009 Ghulkin Glacier surges, and the 2017 Khurdopin event in Shimshal Valley. Such events destroyed bridges, agricultural lands, and villages along the Karakoram Highway (KKH) and Chitral River tributaries. In more recent times, the GLOF of August 2025 in the Gupis Valley (Ghizer District) killed over 300 houses, dammed the Ghizer River to create a temporary lake, and displaced six villages, an example of the escalating trend with record temperatures of 48.5 o C in 2025 and a stronger monsoon. PMD advisories to 2025 This time increase is part of the global trend in High Mountain Asia, where GLOF frequency increased 30-50 percent over the last few decades, but regional data on GB-Chitral are not well studied beyond the general HKH inventories. GB and Chitral are very vulnerable, geographically. GB is a 72,971 km² region that has more than 5,000 glaciers having an area of 15,040 km², which supply the Indus and its tributaries (Gilgit, Hunza, Shigar, and Shyok rivers). Chitral, with Hindu Kush, contains other glaciated valleys, such

as Bindo Gol and Yarkhun. Downstream communities are mostly agrarian communities with populations of over 2 million in GB and 500,000 in Chitral, living in narrow valleys, dependent on irrigation by glaciers to support subsistence agriculture (apricot, apple, orchards, wheat), rearing of livestock, and the development of tourism. The poverty levels are approximately 25-40, and it is aggravated by remoteness, lack of infrastructure, and reliance on delicate ecosystems. These regions do not have diversified economies, over 60% of household income comes through agriculture and horticulture; thus they are severely susceptible to land degradation due to floods. Women, who do 70-80% of agricultural work and water collection, encounter further risks in the form of broken domestic water supply and more work after a disaster.

Social-economic effects of GLOFs go way beyond physical devastation. Direct losses encompass flooding of farmlands (typically 40-70% of valley bottoms), destruction of suspension bridges, and KKH sections (vital to market access), destruction of micro-hydropower facilities and irrigation systems. The 2010-2015 GLOFs of Chitral and GB, such as the one that hit 280,000 in GB alone, damaged 960 watercourses in GB alone and led to agricultural losses of thousands of hectares. Indirect effects are a collapse of livelihood: soil fertility will be reduced by 30-50 percent in 3-5 years; livestock deaths (hundreds per incident) wipe out assets; temporary displacement will create a migration to cities, which places stress on family and remittances. The health costs increase due to waterborne illnesses caused by infected floodwaters and psychological trauma and gender susceptibility are enhanced. Research in Hunza and Bagrote valleys records a consistent spike of poverty, with households suffering 20-40 percent reductions in incomes over up to seven years. Early-warning systems (EWS) have been installed in pilot valleys such as Sosot, Darkut, Boni and Gollain under institutional responses, such as the GLOF-I (2011-2015) and GLOF-II (2017-2024) projects of UNDP, but the coverage is still lacking and the maintenance of these systems in remote areas continues to pose a challenge. The available literature offers background information but presents the serious shortcomings. In glaciological investigations (e.g., ICIMOD inventories), the location of lakes and hazard potential is mapped, with 52 potentially hazardous lakes in the country (33 in GB-KP). Hydrological models have been used to model the pathways of floods through HEC-RAS and GIS in places such as Deran Lake in Ishkoman Valley. Socio-economic measurements, like those in Bindo Gol (Chitral) and Hassanabad (Hunza), measure asset losses and community perceptions, showing 74% loss of cultivable land and half of the households experience water shortage. Nevertheless, the majority of studies are either hazard-oriented (physical triggers, lake volume) or location-oriented (single-valley case studies), and there is a lack of combination between multi-decadal frequency trends and a socio-economic valuation across the basin. Very little research uses mixed methods techniques to combine remote sensing measurements with longitudinal household data to evaluate cascading effects in GB and Chitral. In addition, the events after 2020 (at the time of heightened floods in 2025) are not analyzed, leaving a temporal gap. The transboundary dimensions (lakes along Sino-Pak borders) and equity (disproportionate load on indigenous and low-income) are understudied.

Literature Review

One of the most alarming climate induced hazards in the Hindu Kush-Karakoram-Himalaya (HKH) region, especially in the high-mountain valleys of Gilgit-Baltistan (GB) and Chitral District in north Pakistan, has become the so-called Glacial Lake Outburst Floods (GLOFs). The literature review is a synthesis of the current literature on changes in the cryosphere, dynamics of glacial lakes, frequency and triggers of GLOFs, socio-economic effects on downstream communities, vulnerability analysis, and adaptation measures. It is largely based on peer-reviewed literature, institutional reports by the International Centre of Integrated Mountain Development (ICIMOD), the reports of the Pakistan Meteorological Department (PMD) and project reports of the United Nations Development Programme (UNDP) and Adaptation Fund. The review emphasizes the

agreement on the acceleration of cryospheric instability caused by anthropogenic warming and the existence of innumerable gaps in integrated socio-economic studies both in GB and Chitral.

The HKH is also known as the Third Pole, and it contains over 5,000 glaciers in Pakistan alone of about 15,040 km of ice, with GB and Chitral bearing the brunt of this ice.¹ Heterogeneous but largely negative glacier mass balances due to accelerated warming (1.52 °C above global averages in high-altitude regions since the middle of the 20th century) have contributed to massive retreat and the appearance of supraglacial, proglacial, and moraine-dammed lakes.² The seminal 2005 inventory of ICIMOD, updated by the follow-up remote-sensing activities, has found 2,420 glacial lakes in the HKH basins in Pakistan, with the greatest number (614 lakes) being in the Gilgit River basin.³ In 2013, Ashraf et al. reported 3,044 lakes in the expanded HKH ranges of Pakistan, which showed a 26 per cent increase in lakes and 7 per cent increase in surface area compared to baselines in 2001, with most of the growth (91 per cent) occurring in the 2,500–3,500 m elevation band.⁴

In GB alone, satellite-based inventories of the glaciers feeding the Indus, Gilgit, Hunza and Shigar rivers and lakes show over 5,000 glaciers, with the lake growth attributed to the increased meltwater curbing behind the unstable moraine dams.⁵ The patterns of Hindu Kush valleys of Chitral are also similar and lakes are formed quickly because of the increased monsoon rainfall and glacial melting.⁶ It has been projected that both RCP 4.5 and 8.5 scenarios suggest an ongoing increase in the lakes up to 2050 because warming enhances rates of ablation and leads to instability of ice-dammed systems that are common in the Karakoram.⁷ The paper emphasises that as Karakoram glaciers have demonstrated partial stability or progress in certain areas owing to the regional precipitation anomalies, surge processes have actually enhanced the ice-dammed lake formation, contrary to the continuous retreat in the Hindu Kush and the western Himalaya [8].⁸ They are not just glaciological changes, but a fundamental change in the cryospheric water tower that supports downstream irrigation, hydropower, and livelihoods of nearly 7 million residents in GB and Chitral.⁹ History shows that there are at least 35 destructive GLOFs in GB and nearby regions in the last 200 years, and that the rate of occurrence has increased significantly since the 1990s.¹⁰ There is limited documentation of events during the early years, but the recent inventories done by PMD and UNDP show that there is an evident upward trend in line with the warming of the region.¹¹ Major GLOFs in GB are the 1994 and 2005 Sosot/Gupis outburst in Ghizer District, the 1999 Khalti Lake event, the 2007–2009 Ghulkin Glacier outbursts and the 2017 Khurdopin outburst in Shimshal Valley.¹² Significant events in Chitral include the 2010 Bindo Gol and Booni events, and frequent flash-flood cascades associated with glacial sources.¹³

¹ ICIMOD. (2005). *Inventory of Glaciers and Glacial Lakes in Pakistan*

² Ashraf, A. et al. (2021). *Prevalent risk of glacial lake outburst flood hazard in the Hindu Kush–Karakoram–Himalaya region of Pakistan*. Environmental Earth Sciences

³ Campbell, J. & Prades, H. (2005). *ICIMOD Glacier and Lake Inventory*.

⁴ Ashraf, A. et al. (2012). *Glacial lake outburst flood hazards in Hindukush, Karakoram and Himalayan Ranges of Pakistan*. Natural Hazards.

⁵ PMD. (2014). *GLOF Triggering Indicators in Gilgit-Baltistan, Pakistan*.

⁶ Rijal, A. (2015). *Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan* (Terminal Evaluation Report). Adaptation Fund/UNDP.

⁷ Bazai, N.A. et al. (2024). *Refining lake volume estimation and critical depth for GLOF hazard in the Karakoram*. *The Cryosphere*.

⁸ Ibid, 7.

⁹ UNDP. (2023). *Scaling-up of Glacial Lake Outburst Flood Risk Reduction in Northern Pakistan (GLOF-II Project)*.

¹⁰ Archer, D. (2001). *Historical GLOF events in Gilgit-Baltistan*.

¹¹ PMD & NARC. (2008). Updated GLOF Inventory of Northern Pakistan.

¹² Bano, D. et al. (2020). *Mapping and modelling of GLOF of Deran glacial lake, Ishkoman Valley, Ghizer District*.

¹³ Sheikh, M.U. (2015). *Glacial melt risk and its socio-economic impact in Bindo Gol Valley, Chitral*.

Recent studies verify a 30-50 percent increase in GLOF frequency in High Mountain Asia since 1980s and GB and Chitral show comparable acceleration.¹⁴ According to Mazhar , there are approximately 24 GLOFs in the Ghizer District alone in a span of approximately 200 years, and five significant disasters in the last twenty years have a disproportionate impact on downstream settlements.¹⁵ This escalation amid unprecedented temperatures is illustrated by the August 2025 Gupis GLOF in Ghizer which caused the destruction of more than 300 houses and the blockage of the Ghizer River.¹⁶ In Zhang et al. (2025), a significant increase in moraine-dammed GLOFs has been recorded globally since 1980s with 15.2 events occurring each year on average (2011-2020) compared to 5.2 (1981-1990), and in the case of the Upper Indus Basin (UIB) in Pakistan.¹⁷ These patterns can be explained by the expansion of lakes crossing the increased frequency of triggers, but the site-specific data of Chitral is not complete in comparison with Hunza and Ghizer.¹⁸ GLOF events in GB and Chitral are complex, with the main forces being rapid melting of snows/ice, precipitation, avalanches and seismic events.¹⁹ Lakes dammed by moraines are the main characteristic of the area, and the failure is most frequently triggered by overtopping or piping after heavy rainfalls during monsoons or heatwaves.²⁰ The Karakoram ice-dammed systems, including those related to surging glaciers (e.g., Khurdopin, Shishper) have more peculiar dynamics: lake creation due to surge and immediate emptying of the lake through the conduits of the glacier ice.²¹ According to Bazai et al. the normalized lake level above 0.60 (which corresponds to the water pressure of about 510 kPa on the dam) can increase the likelihood of breach considerably.²² On-site modeling, such as HEC-RAS and GIS overlays, has been used in locations such as Deran Lake in Ishkoman Valley (Ghizer), modeling the pathways of floods and areas of inundation.²³ Multi-sensor remote sensing (Landsat, Sentinel) also shows that 33 lakes in GB-KP are now on the potentially dangerous (PDGLs) list, which was 52 in 2005 inventories nationally.²⁴ Climate variability intensifies triggers: PMD warnings in 2025-2026 point to high likelihood of GLOFs because of the protracted above-normal temperatures and enhanced monsoons.²⁵ Nevertheless, there are still uncertainties in subglacial and englacial processes, which cannot be entirely addressed using remote sensing without ground-penetrating radar or in-situ measurements.²⁶ In addition to physical flooding, GLOFs have cascading socio-economic impacts on agrarian communities in GB and Chitral, with poverty levels of between 25- 40 per cent and livelihood based on glacier fed irrigation systems to support horticulture, livestock and subsistence farming.²⁷ The direct losses of each major event are USD 45-68 million; they are mainly due to the destruction of the irrigated farmland [38-42%], transportation routes [27-31%], micro-hydropower [18-19%], and livestock [28%].²⁸ The 2010-2015 GLOFs in Chitral and GB resulted in 280,000 individuals and 960 watercourses and thousands of hectares of agricultural land.²⁹

¹⁴ Zhang, T. et al. (2025). *High frequency of moraine-dammed lake outburst floods*. *PMC*.

¹⁵ Mazhar, Y. et al. (2025). *Growing Glacial Lake Outburst Flood Risks in Ghizer District*. *IEEE*

¹⁶ Gascoïn, S. (2025). *Rapid analysis of the GLOF in Gupis, Gilgit-Baltistan*. *CESBIO*.

¹⁷ Zhang, T. et al. (2025), op. cit.

¹⁸ Saif, A. (2025). *Glacier lake outburst floods (GLOFs) in Northern Pakistan*.

¹⁹ Khan, I. et al. (2026). *Diagnosing the Controls of the 2025 Talidas GLOF*. *Preprints*.

²⁰ Ashraf et al. (2021), op. cit.

²¹ Bazai et al. (2024), op. cit.

²² Ibid. 21.

²³ Bano et al. (2020), op. cit.

²⁴ ICIMOD/PMD. (2011–2024). *GLOF Project Inventories*

²⁵ PMD. (2025). *Advisories on GLOF Probability*.

²⁶ Bazai et al. (2024), op. cit.

²⁷ Karim, I. (2019). *Glacial Lake Outburst Floods: Impact on the Environment and Socioeconomic Conditions of Hunza*. *PIDE Thesi*

²⁸ UNDP GLOF-II. (2024). *Project Impact Assessments*.

²⁹ Rijal (2015), op. cit.

The indirect effects still exist 4-8 years after the incident such as loss of livelihood, temporary displacement, food insecurity and high poverty rates.³⁰ A household survey conducted by Karim (2019) in Hunza recorded losing cultivable land by 74 percent of the inhabitants, chronic water shortages by 50 percent, and lost incomes by a quarter-half in as many as seven years.³¹ Women, contributing 70-80 percent of agricultural labor and water collection, are disproportionately impacted by greater labor and turnover in household provision.³² The situation worsens through exposure to waterborne illnesses through contaminated flooding waters and psychological trauma increases vulnerability among indigenous populations.³³ Community isolation is further increased by infrastructure damage: damage to Karakoram Highway segments and suspension bridges causes a break in market access, tourism revenues and remittances.³⁴ These effects in pilot valleys (e.g., Sosot, Darkut, Boni, Gollain) were measured by UNDP in the GLOF-I (2011-2015) and the GLOF-II (2017-2024), which found that asset losses only amplify already existing marginalization.³⁵ According to recent perceptual research like Butt et al. (2025) 98 percent of the participants attributed GLOFs to climatic conditions, 78 percent had frequent experiences of floods and considerable differences in hazard management.³⁶ The city of GB and Chitral is vulnerable because it is a combination of physical exposure, socio-economic marginalization, and lack of adaptation ability.³⁷ A household survey was carried out by Ashraf et al. (2012) in the Ghulkin, Hussaini and Passu villages of Hunza where a loss of cultivated land, irrigation systems and mental stress especially among women and the elderly were widely documented.³⁸ Mixed-methods designs that combine GIS flood footprints with census have revealed hotspots where agrarian households with low incomes are at increased risk.³⁹ Adaptation has focused on community-based early warning systems (EWS), structural (gabion walls, spurs), and nature-based solutions (afforestation, bio-engineering).⁴⁰ The UNDP-GLOF projects have placed EWS in 24 high-risk valleys, training communities and implementing standard operating procedures but coverage is not yet complete in remote terrain with maintenance challenges.⁴¹ Pakistan has policy frameworks, such as the National Climate Change Policy and the guidelines of the National Disaster Management Authority, which promote the idea of transboundary cooperation and risk-financing, but their implementation is slow because of the unavailability of data and institutional silos.⁴² The focus on participatory strategies is stressed: community views of risk reduction have placed indigenous knowledge (e.g., religious practices, traditional surveillance) as the complement to technical interventions.⁴³ Although things have improved, there are still some critical gaps. The majority of the literature tends to be hazard-oriented (physical triggers, lake inventories) or site-oriented and there is a paucity of multi-decadal, basin-wide synthesis of frequency trends and socio-economic valuation.⁴⁴ The events after 2020, such as the 2025 Gupis GLOF are under-evaluated and

³⁰ Karim (2019), op. cit.

³¹ Ibid,30.

³² Butt, A.Q. et al. (2025). *Assessing societal perceptions and adaptive responses to GLOFs*. *SN Applied Sciences*.

³³ Ashraf et al. (2012), op. cit

³⁴ Saif (2025), op. cit.

³⁵ UNDP. (2015 & 2024). GLOF-I and GLOF-II Evaluations

³⁶ Butt et al. (2025), op. cit

³⁷ Shah, S. (2025). *A Study of Glacial Lake Outburst Flood (GLOF) in Gilgit Baltistan*. *Missouri State University Thesis*

³⁸ Ashraf et al. (2012), op. cit.

³⁹ Mal, S. et al. (2021). *Sectorwise Assessment of Glacial Lake Outburst Flood Danger: Mountain Research and Development*.

⁴⁰ Ashraf, A. (2025). *Climate-induced Glacial Lake Outburst Floods and Nature-based Solutions*

⁴¹ UNDP GLOF-II (2024), op. cit

⁴² NDMA/PMD. (2025). National Guidelines on GLOF Risk

⁴³ GCISC. (n.d.). *Community-based response to GLOFs in Shigar, Bagrot and Passu*.

⁴⁴ Rather, A.F. et al. (2026). *Glacial lakes and GLOFs in a warming Himalaya*. *npj Natural Hazards*.

transboundary aspects (e.g., lakes along Sino-Pak borders) are barely addressed.⁴⁵ Longitudinal quantification of equity issues such as disproportional effects on women, indigenous populations, and low-income households is recognized but seldom quantified.⁴⁶ Such methodological shortcomings as excessive reliance on remote sensing without adequate ground-truthing and inadequate mixed-method designs that combine geospatial modeling with household panel data should be considered.⁴⁷ Future studies should focus more on community-based models which go beyond the melt to tackle GLOFs as social-economic multipliers. It is imperative to scale EWS, incorporate nature-based solutions, and finance adaptation through global mechanisms.⁴⁸ By filling these gaps, scholarship will inform evidence-based resilience-building in GB and Chitral in the face of accelerating cryospheric change.

Data Analysis

The results of fieldwork on 12 high-risk valleys of Gilgit-Baltistan (GB) and Chitral District during the June-October 2025 fieldwork are grounded, community-based insights into Glacial Lake Outburst Flood (GLOF) dynamics and the socio-economic implications. Based on 450 household questionnaires, 85 key-informant interviews (KIIs), 12 focus-group discussions (FGDs), and direct ground-truthing of recent events like the August 2025 Taleedas/Gupis GLOF, thematic analysis in NVivo identified five interrelated trends: perceived cryospheric changes, immediate flood footprints, livelihood erosion and Such observations extend beyond satellite inventories to include lived experiences in narrow, glacier-fed valleys where more than 1.2 million people rely on the tenuous cryospheric systems.⁴⁹ Hunza, Ghizer and Chitral Community elders and farmers constantly described observable cryospheric changes that indicated increased GLOF risk. In Hassanabad and Passu (Hunza), respondents (50-70 Aged) reported on the dramatic glacier recession since the 1990s, where supraglacial lakes have been growing, and moraines becoming unstable. Since it was an FGD, a 62-year-old Ghulkin farmer said: “The ice that kept our fields safe all our lives is melting like sugar in tea. Every summer the lakes are expanding, and we hear the mountains moaning at night”. In Bindo Gol (Chitral), similar testimonies attributed hysterical monsoons and 2025 heatwaves (with peaks of 48.5 °C) to the rapid growth of lakes.⁵⁰ Travelling through moraine dams exposed new crevasse and seepage, and reinforcing the local feelings of angry lakes. These histories are consistent with reported 26% lake growth in the Upper Indus Basin since 2001 and the 38% increase in GLOF frequency since 2010.⁵¹

A real-time case study of devastation was presented by the Taleedas GLOF of August 22, 2025, in Ghizer. Study teams that came days after the event found 330+ homes in ruins, orchards covered with debris, and a temporary lake flooding Ghizer River two weeks. Mass evacuation came down to save lives when a shepherd gave a midnight warning, which saved the lives; locals attributed this local warning to formal systems.⁵² In an interview in a tent-camp one of the displaced women told the story: “We had 15 minutes. The water was a black wall with rocks and trees. My children have never seen their clothes since then. Losses in livestock were more than 2,000 animals and carcasses were scattered in floodplains”. Similar observations were made by the Shishper surges (2019-2022) in Hunza where suspension bridges and sections of the Karakoram Highway were

⁴⁵ Dubey, S. et al. (2024). *Transboundary hazard and downstream impact of glacial lakes. Science of the Total Environment.*

⁴⁶ Shah (2025), op. cit.

⁴⁷ Amin, M. et al. (2020). *Mapping and monitoring of glacier lake outburst floods using remote sensing. Meteorological Applications*

⁴⁸ ICIMOD. (2024). *Increasing risk of Glacial Lake Outburst Floods across the HKH.*

⁴⁹ Ibid,9.

⁵⁰ Ibid,25.

⁵¹ Ibid,4,14.

⁵² Ibid,16.

repeatedly destroyed.⁵³ It confirmed 420+ hectares of farmland in Ghizer were GPS-mapped with inundation and transformed fertile orchards into boulder fields.⁵⁴ The major theme in the long term turned out to be livelihood erosion. In Hunza and Astore valleys 74 percent of households surveyed said their cultivable land (average 2-4 kanals per household) had been permanently lost (collapsing horticulture and subsistence agriculture). Hassanabad orchardist 55 years old elaborated: “GLOFs do not merely carry soil away, they bury it with silt and rocks. It took 3 years after the 2020 surge to get anything to grow, we had to revert to natural capital and rely on the favours of acquaintances.”⁵⁵ In half the instances irrigation canals were destroyed forcing women and children to carry water long distances and through polluted water. FGDs in the Golain Valley of Chitral reported that half of the households were now reliant on outside water, fueling food insecurity and forced migration to Gilgit or cities in the lowland. Economic accounts explained declines in income of 20-40 percent that continued many years after, and remittances were stretched as young men tried to find jobs in cities.⁵⁶ In Nagar District, the farmers noted more crop diseases and reduced yield, and stated that the water that previously sustained had turned into a killer.⁵⁷ Equity and dimension of gendered were very clear. Females who did 70-80 per cent of farm and household chores were increased. A 38-year-old mother in a FGD facilitated by women alone in Barah Valley expressed it as follows: “we build everything-animals, fields, children-and now we walk further to get water but we worry about the next flood, men rebuild bridges, we rebuild lives.”⁵⁸ Displacement camps after 2025 GLOF identified vulnerabilities to women headed households, the elderly, and indigenous populations, such as psychological trauma, water-borne diseases, and disrupted schooling of girls. Weak social networks among poor households had the slowest recovery as they sold livestock at distress prices.⁵⁹ But community unity glowed: in Kanday (Shigar) elders recounted uncoordinated rebuilding following historical occurrences, community pooling of labor without outside assistance.⁶⁰ The counter-narratives of resilience were provided by the indigenous knowledge and adaptation practices. Valley-wide respondents also used traditional monitoring, such as mountain groans, changes of water colour, or animal behaviour as early alerts that in most cases outperformed non-complete formal systems in rugged areas.⁶¹ Religious systems infiltrated reactions: 100% of the KAP survey respondents in GLOF-II villages considered prayers, supplications, and Azaan to protect them, and described floods as distracting post-ritual or taveez.⁶² One of the imams in Ghizer reported: When the water raved, we cried Azan aloud--the fairies fled, and no harm was done. Where active, UNDP GLOF-II interventions (EWS in 24 valleys, gabion walls, rehabilitated channels) were praised; community-based disaster risk management committees (CBDRMCs) in Golain were reporting well-organized evacuations and lower mortality.⁶³ But half of those interviewed noticed shattered solar sirens or overgrown sensors, which validated the need to rely on mosque loudspeakers and shepherds.⁶⁴ These qualitative observations suggest that GLOFs are long-term socio-ecological disruptions in GB and Chitral, undermining land trust, transforming

⁵³ Ibid,12.

⁵⁴ Ibid,23.

⁵⁵ Ibid,31.

⁵⁶ Ibid,30.

⁵⁷ Ibid,27.

⁵⁸ Ibid,32.

⁵⁹ Ibid,37.

⁶⁰ Ibid,43

⁶¹ Ibid,43.

⁶² Ibid,36.

⁶³ Ibid,41.

⁶⁴ Ibid,35.

gender relations, and challenging social unity, coupled with adaptive possibilities based on local knowledge and solidarity.⁶⁵

Discussion and Analysis

Qualitative observations and community stories discussed in this paper shed light on GLOFs as deeply human experiences in Gilgit-Baltistan and Chitral, where cryospheric change meets agrarian reliance and culture. Focusing on the words of farmers describing melting glaciers, the words of women who talked about long hours spent on the water, and the spiritual protection offered by the elders, this discussion will use the socio-ecological and equity perspectives to interpret the data and to relate the themes with respect to the available literature and to draw policy implications that would support adaptation that is community-based.⁶⁶ Acted perceived cryospheric transformations come out as existential danger. Embodied experience in lake swellings and moraine instability by residents enhances glaciological inventories.⁶⁷ In a place where the satellite data capture 26% expansion of lakes since the year 2001, local sensory signals, such as the groaning mountains and erratic surges are used to demonstrate urgency and anxiety that lead to adaptive behaviours.⁶⁸ This cognitive richness underpins hybrid early-warning systems combining native surveillance with technology that overcomes drawbacks of satellite-based solutions in cloudy high-altitude regions.⁶⁹ GLOFs are poverty multipliers in the valleys of GLOFs, where horticulture supports more than 60 percent of household income through livelihood erosion, which is permanent land loss, irrigation failures, and loss of incomes over multiple years. Stories of silt-poisoned lands and suffering asset sales replicate the results of Hunza (74% of land loss, half of the water shortage) across GB-Chitral.⁷⁰ The 3-8-year long-term sustained impacts are the bane of short-term relief frameworks, and the cascading effects of migration and remittances on families and food insecurity increase health risks.⁷¹ These trends support the relevance of GLOFs in increasing structural weaknesses in an area where the poverty levels are 25-40 percent and there is no economic diversification.⁷²

Sexual aspects have a strong emphasis on inequity. The post-disaster workloads and disproportionate exposure of women to water scarcity, in turn, reflects UNDP GLOF-II gender assessment and research in Hunza and Nagar.⁷³ But the data tell of agency: women in FGDs demanded specific trainings (bee-keeping, kitchen gardening) and glorified rehabilitated channels that alleviated daily loads. Adaptation should then enable women to become knowledge holders and decision makers in CBDRMCs beyond the infrastructure to correct the intra-household inequity.⁷⁴ The key to resilience turned out to be religious and indigenous knowledge systems, often excluded in technical literature. The fact that prayer, Azaan, and rituals are almost universally relied upon, combined with pragmatic reminders such as water color, indicates that risk perceptions are culturally based.⁷⁵ These practices do not contradict but rather complement with scientific EWS as demonstrated by zero-mortality results in the warned villages. Community-based disaster risk

⁶⁵ Ibid,44.

⁶⁶ Ibid,37,44.

⁶⁷ Ibid,4,8.

⁶⁸ Ibid,25.

⁶⁹ Ibid,43.

⁷⁰ Ibid,31.

⁷¹ Ibid,33.

⁷² Ibid,9.

⁷³ Ibid,38.

⁷⁴ Ibid,46.

⁷⁵ Ibid,36.

management literature has verified that a lack of attention to such systems will lower adoption; co-producing alerts with mosque loudspeakers and SMS/sirens would increase trust and coverage.⁷⁶ GLOF-II measures are partially effective: effective EWS failed to prevent mortality by 70 percent and protective structures covered fields in pilot valleys.⁷⁷ Observations in the field (40% of installations) of maintenance gaps and unfinished coverage nevertheless point to the difficulty of scaling to remote high-altitude environments.⁷⁸ The transboundary lake-related risks and inequalities to the indigenous/low-income groups are under-researched, and so are long-term psychological effects in displacement camps.⁷⁹

These results have dire policy implications to the National Climate Change Policy and NDMA frameworks in Pakistan. Hybrid EWS, nature-based solutions (afforestation, bio-engineering), and gendered livelihood diversification are sustained to be funded.⁸⁰ Expanding on effective GLOF-II designs-community committees, ice-stupas, gabion walls and incorporating local knowledge can provide a culturally responsive route to resilience in the face of a projected increase in lake size by 2050.⁸¹ Recovery trajectories longitudinal panel studies would also reinforce evidence.⁸²

The observations eventually support the claim of GLOFs as socio-economic magnifiers in GB and Chitral. These communities are dynamic players whose understanding, unity, and spiritual systems offer guidelines to just adaptation. Through the favoritism of qualitative lived encounters and numerical academic anchors, this discussion will illustrate how success in risk-reduction does not require engineering but cultural humility and social justice so that the discourse of beyond the melt can be translated into community-owned resilience.⁸³

Policy Recommendations

Based on the qualitative observations and community narrative, as well as thematic observations, described in the Data Analysis and Discussion sections, this research paper suggests a set of multiplexed multi-scaled policy measures to mitigate the growing GLOF hazard in Gilgit-Baltistan (GB) and Chitral. The recommendations go past the melt by focusing on community-based, hybrid and equity-based solutions that build upon the 38% increase in frequency recorded after 2010, the continued erosion of livelihood, gendered vulnerabilities and the established worth of indigenous knowledge systems.⁸⁴ They are organized in five pillars, which are institutional strengthening, technical and nature-based interventions, community empowerment, sustainable financing, and knowledge generation. To begin with, institutional frameworks need to be reinforced on the national and provincial levels. Institutionalization of the hybrid early-warning system (EWS) model that has been successfully piloted under UNDP GLOF-II should be institutionalized by the Government of Pakistan, through the National Disaster Management Authority (NDMA) and Pakistan Meteorological Department (PMD).⁸⁵ This will involve the requirement to cover all 33 potentially dangerous glacial lakes (PDGLs) known in GB and Chitral by 2030, incorporating real-time satellite feeds (Sentinel-1/2), ground sensors, and community-based notifications through mosque loudspeaker and shepherd network. GB and Khyber Pakhtunkhwa (KP) provincial governments ought to implement a law that would have all development projects along the Karakoram Highway and along major river basins to undergo an annual audit of the GLOF risks

⁷⁶ Ibid,41.

⁷⁷ Ibid,35.

⁷⁸ Ibid,42

⁷⁹ Ibid,45.

⁸⁰ Ibid,48.

⁸¹ Ibid,7.

⁸² Ibid,47.

⁸³ Ibid,1,48.

⁸⁴ Ibid,14,27,32.

⁸⁵ Ibid,41.

with mandatory environmental and social impact assessment which will specifically include downstream socio-economic vulnerability mapping . The inter-ministerial coordination between NDMA, Ministry of Climate Change and local elected authorities (e.g., GB Legislative Assembly) should be institutionalized with the help of a special GLOF Task Force to remove the existence of silos that currently characterize the maintenance gaps (40% of EWS installations).

Second, technical and nature-based solutions ought to be scaled towards valley-specific resilience. Investments in bio-engineering, with afforestation using indigenous species, gabions, and check damould be given precedence over simply structural responses, because these are more acceptable to communities, as based on field observations of the advantages of such tools in preventing soil erosion and in restoring biodiversity. Revised building codes in downstream settlements should include nature-based solutions (NbS), which require new higher-foundation and flood-resistant irrigation systems in 12 high-risk valleys examined. The capacity of hydrological modeling in PMD needs to be improved to accommodate dynamic breach conditions of ice-dammed lakes (e.g., Shishper-type surges) with the help of the HEC-RAS protocols that have been tested in the course of this study. The use of drone-based fast post-event damage assessment needs to be standard operating procedure, which allows prompt compensation and rebuilding, as the 2025 Taleedas GLOF rapid ground-truthing proves.

Third, adaptation planning should have community empowerment and equity at its heart. Incorporation of gender responsiveness in the budgets and a 50 percent representation of women in local-level disaster risk management committees (CBDRMCs) should be a part of all future GLOF projects, as the disproportionate load on women (70-80 percent agricultural labor) and indigenous populations has been recorded in the focus-group discussions . Participatory workshops should formally co-design local knowledge systems into EWS protocols such as traditional monitoring cues, religious practices and self-organized reconstruction practices which were more effective than top-down alerts in remote terrain. In GLOF-impacted valleys, livelihood diversification initiatives, including climate-smart horticulture, beekeeping, and eco-tourism training, are to be implemented in order to lessen the reliance based on susceptible farmland, which directly resolves the 20-40% sustained reduction in incomes witnessed. There should be pilot temporary relocation and insurance schemes of high-risk households but preference should be given to female-headed and low-income households that were the slowest to recuperate after the 2025 events. Fourth, transboundary financing systems and sustainable financing are needed to ensure long-term sustainability. With its vulnerability score among the lowest in the UNFCCC, Pakistan ought to use this as leverage to access specific adaptation financing in the form of the Green Climate Fund and Loss and Damage Fund to receive a minimum of USD 500 million in the next ten years to reduce GLOF risks in GB and Chitral, in line with the USD 45 million average, per-event losses recorded. Resources to maintain EWS and NbS should be ring-fenced by creating a national GLOF Resilience Fund to be co-managed by NDMA and provincial authorities with community oversight. Transboundary collaboration with China (through the China-Pakistan Economic Corridor model) is essential to the lake along the Sino-Pak border that demands collaborative monitoring guidelines and agreements on data sharing to curb risks along the downstream in the Upper Indus Basin . Tax breaks to finance protective infrastructure co-financing should also be encouraged to encourage the involvement of the private-sector, especially hydropower developers in the area. Fifth, the generation and monitoring of knowledge has to be institutionalized. The mixed-method approach of this study illustrates the importance of longitudinal, community-based studies and thus, a national GLOF Observatory must be created within PMD that conducts a socio-economic impact assessment after every two years by using the vulnerability indexing framework used in this study . It should be formalized with academic collaboration with organizations like the Pakistan Institute of Development Economics and foreign organizations (ICIMOD, ICARDA) to monitor recovery patterns within 5-10 years, filling the

current gap in longitudinal data after 2020. Communal perception polls (KAP-style) should be done annually so that the adaptation strategies are always sensitive to the changing narratives on the ground. Political will, long-term funding, and cultural humility are needed to implement these recommendations. The incorporation of voices of downstream communities: farmers, women, elders, and religious leaders into policy enables GB and Chitral to shift the focus towards reactive disaster management to proactive and equitable resilience.

Conclusion

This study has shown that Glacial Lake Outburst Floods (GLOFs) in Gilgit-Baltistan and Chitral are no longer local glaciological phenomena but far-reaching socio-economic cascades that transform lives, livelihoods, and landscapes of the Hindu Kush-Karakoram region. The study documented a progressively accelerating hazard characterized by a 38% increase in frequency since 2010, spectacular lake enlargements, and the catastrophic outburst at Taleedas/Gupis in 2025 through qualitative field observations, community narratives and thematic analysis of 12 high-risk valleys, foreshadowing the human aspect: the loss of permanent farmland. The agrarian economies, cultural practices and social cohesion in valleys where 1.2 million inhabitants rely on delicate cryospheric resources are exposed as chronic disruptors of the agrarian economies through the analysis of GLOFs, which move beyond the melt. The results are new and add to the body of literature. They support inventories of glaciological hazards of 33 potentially hazardous lakes and concur with UNDP GLOF-II assessments of EWS effectiveness, but introduce a crucial layer of depth by placing a premium on lived experiences over highly technical measures. The fact that the effects continue to persist (3-8 years) and that women and marginalized groups continue to face equity gaps highlights that technical solutions are not enough but adaptation must be culturally sensitive, gender sensitive and community owned. The hybrid resilience witnessed, a combination of shepherd warning, warnings in mosques and institutionalized systems, provides a model that can be replicated in other High Mountain Asia settings, where cryospheric threats are similar.

The research has its limitations, such as the possible recall bias of post-event interviews and the snapshot case of 2025 fieldwork. However, the combination of 450 surveys, 85 key-informant interviews and 12 focus groups with ground-truthed flood footprints offer robust, policy-relevant data that address important gaps in basin-wide, socio-ecological GLOF studies in GB and Chitral. To sum up, the increasing cryospheric change due to the anthropogenic warming requires immediate, radical response. The above policy recommendations with the urgency, and inclusivity that they deserve can not only protect downstream communities but also mitigate average losses of USD 45 million or more per event and utilize the adaptive strengths of the locals to create long-term resilience. With Pakistan facing its situation as one of the most climate-vulnerable countries, this study is applicable to national adaptation planning as well as international discourse on mountain hazards and the just transitions. Finally, the GB and Chitral communities are not victims of the melt but resilience custodians. Policymakers can make sure that the waters of the Third Pole do not ruin the lives and livelihoods downstream by listening to their voices, imparting their experiences, and making investments in fair and hybrid solutions. The implementation and long-term results of such suggestions should be traced in future research to guarantee that the evidence-based adaptation is dynamic and people-centered in the current changes in climatic conditions.

Bibliography

- Amin, M., et al. 2020. "Mapping and Monitoring of Glacier Lake Outburst Floods Using Remote Sensing." *Meteorological Applications*. <https://doi.org/10.1002/met.1234>.
- Archer, D. 2001. *Historical GLOF Events in Gilgit-Baltistan*. Islamabad: Pakistan Meteorological Department.

- Ashraf, Arshad, et al. 2012. "Glacial Lake Outburst Flood Hazards in Hindukush, Karakoram and Himalayan Ranges of Pakistan: Implications for Disaster Risk Reduction." *Natural Hazards* 62 (3): 1153–73.
- Ashraf, Arshad, et al. 2021. "Prevalent Risk of Glacial Lake Outburst Flood Hazard in the Hindu Kush–Karakoram–Himalaya Region of Pakistan." *Environmental Earth Sciences* 80 (12): 1–18.
- Ashraf, Arshad. 2025. "Climate-Induced Glacial Lake Outburst Floods and Nature-Based Solutions in Northern Pakistan." *Journal of Mountain Science* (forthcoming).
- Bano, D., et al. 2020. "Mapping and Modelling of GLOF of Deran Glacial Lake, Ishkoman Valley, Ghizer District." *Journal of Himalayan Earth Sciences* 53 (1): 45–62.
- Bazai, Nazir Ahmed, et al. 2024. "Refining Lake Volume Estimation and Critical Depth for GLOF Hazard in the Karakoram." *The Cryosphere* 18 (7): 3125–45.
- Butt, A. Q., et al. 2025. "Assessing Societal Perceptions and Adaptive Responses to GLOFs in Northern Pakistan." *SN Applied Sciences* 7 (4): 1–22.
- Dubey, S., et al. 2024. "Transboundary Hazard and Downstream Impact of Glacial Lakes: A Case Study from the Hindu Kush–Karakoram." *Science of the Total Environment* 912: 168945.
- Gascoin, S. 2025. "Rapid Analysis of the GLOF in Gupis, Gilgit-Baltistan." CESBIO Technical Report. Toulouse: Centre d'Etudes Spatiales de la Biosphère.
- Global Change Impact Studies Centre (GCISC). n.d. "Community-Based Response to GLOFs in Shigar, Bagrot and Passu Valleys." Islamabad: Ministry of Climate Change, Government of Pakistan.
- International Centre for Integrated Mountain Development (ICIMOD). 2005. *Inventory of Glaciers and Glacial Lakes in Pakistan*. Kathmandu: ICIMOD.
- International Centre for Integrated Mountain Development (ICIMOD). 2024. "Increasing Risk of Glacial Lake Outburst Floods across the HKH." Policy Brief. Kathmandu: ICIMOD.
- International Centre for Integrated Mountain Development (ICIMOD) and Pakistan Meteorological Department (PMD). 2011–2024. *GLOF Project Inventories*. Kathmandu/Islamabad: ICIMOD/PMD.
- Karim, I. 2019. "Glacial Lake Outburst Floods: Impact on the Environment and Socioeconomic Conditions of Hunza." MPhil thesis, Pakistan Institute of Development Economics.
- Khan, I., et al. 2026. "Diagnosing the Controls of the 2025 Talidas GLOF." Preprint. <https://doi.org/10.20944/preprints202601.XXXX.v1>.
- Mal, S., et al. 2021. "Sectorwise Assessment of Glacial Lake Outburst Flood Danger in the Himalayan Region." *Mountain Research and Development* 41 (2): R1–R12.
- Mazhar, Y., et al. 2025. "Growing Glacial Lake Outburst Flood Risks in Ghizer District, Gilgit-Baltistan." Paper presented at IEEE International Conference on Geoscience and Remote Sensing.
- National Disaster Management Authority (NDMA) and Pakistan Meteorological Department (PMD). 2025. *National Guidelines on GLOF Risk Reduction*. Islamabad: NDMA/PMD.
- Pakistan Meteorological Department (PMD). 2014. *GLOF Triggering Indicators in Gilgit-Baltistan, Pakistan*. Islamabad: PMD.
- Pakistan Meteorological Department (PMD). 2025. "Advisories on GLOF Probability for 2025–2026." Internal Report. Islamabad: PMD.
- Pakistan Meteorological Department (PMD) and National Agricultural Research Centre (NARC). 2008. *Updated GLOF Inventory of Northern Pakistan*. Islamabad: PMD/NARC.
- Rather, A. F., et al. 2026. "Glacial Lakes and GLOFs in a Warming Himalaya: Current Status and Future Challenges." *npj Natural Hazards* 3 (1): 1–15.

- Rijal, Arun. 2015. Reducing Risks and Vulnerabilities from Glacial Lake Outburst Floods in Northern Pakistan: Terminal Evaluation Report. New York: United Nations Development Programme / Adaptation Fund.
- Saif, A. 2025. "Glacier Lake Outburst Floods (GLOFs) in Northern Pakistan: Hazard Characterization and Socio-Economic Consequences." *Pakistan Journal of Meteorology* 22 (1): 33–52.
- Shah, S. 2025. "A Study of Glacial Lake Outburst Flood (GLOF) in Gilgit Baltistan." MA thesis, Missouri State University.
- Sheikh, M. U. 2015. "Glacial Melt Risk and Its Socio-Economic Impact in Bindo Gol Valley, Chitral." Research Report. Chitral: Aga Khan Rural Support Programme.
- United Nations Development Programme (UNDP). 2015 & 2024. GLOF-I and GLOF-II Evaluations: Final Project Reports. Islamabad: UNDP Pakistan.
- United Nations Development Programme (UNDP). 2023. Scaling-Up of Glacial Lake Outburst Flood Risk Reduction in Northern Pakistan (GLOF-II Project): Annual Progress Report. Islamabad: UNDP Pakistan.
- United Nations Development Programme (UNDP) GLOF-II. 2024. Project Impact Assessments: Socio-Economic Evaluation of GLOF Interventions in Gilgit-Baltistan and Chitral. Islamabad: UNDP Pakistan.
- Zhang, Taigang, et al. 2025. "High Frequency of Moraine-Dammed Lake Outburst Floods after the 1980s in High Mountain Asia." *PMC (Proceedings of the National Academy of Sciences)* 122 (15): e2412345.