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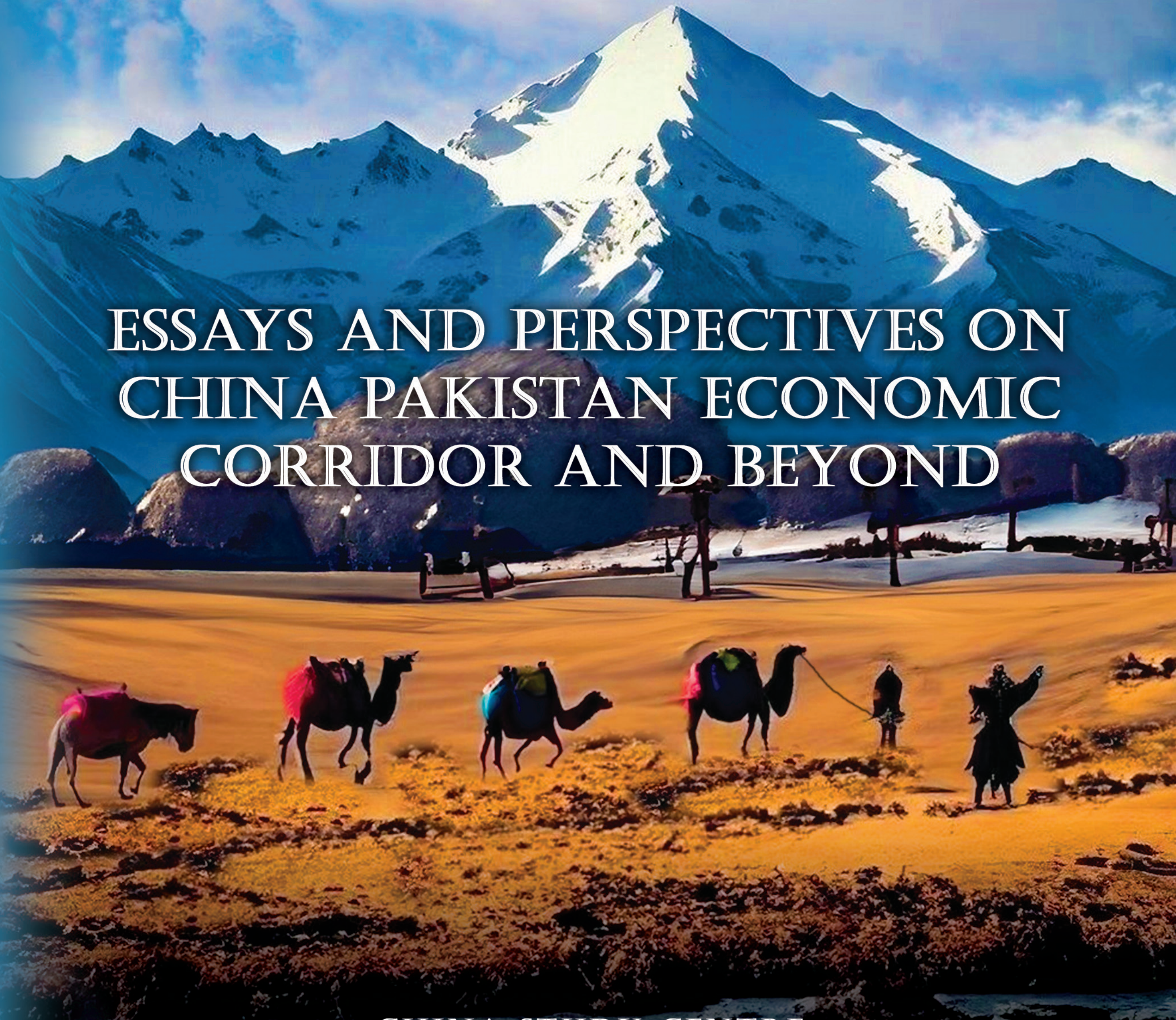
ESSAYS AND PERSPECTIVES ON CHINA PAKISTAN ECONOMIC CORRIDOR AND BEYOND



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KARAKORAM INTERNATIONAL UNIVERSITY
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Geological Hazards along the CPEC Route from Gilgit to Khunjerab

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Introduction

The Karakoram Highway (KKH) is a vital road connecting western China and northern Pakistan. It is a unique geohazards laboratory due to its characteristics, such as steep slopes, active faults, seismic zones, sheared rock mass, and high rainfall (Abbas et al., 2021; Ali, Biermanns, Haider, & Reicherter, 2019). Since its construction, landslides have consistently posed a severe risk, causing numerous disruptions. To address this issue and ensure secure and efficient transportation, we conducted a project to map the susceptibility of landslides along the highway. We employed Geographic Information Systems (GIS) to gather and process data on geology and geomorphology. By considering various factors that contribute to landslides, including lithology, seismic activity, precipitation volume and intensity, faults, elevation, slope angle, aspect, curvature, and hydrology, we created a susceptibility map (Ali et al., 2019).

Spatial and statistical analysis revealed that active faults, seismic activity, and slope angle were the key factors determining the spatial distribution of landslides (Wang, Sassa, & Xu, 2007). The Karakoram Highway traverses one of the world's fastest-growing mountain ranges, characterized by intense geodynamic activity resulting from earthquakes, glacier erosion, river incision, periglacial action, and unexpected monsoonal rainfall (Lilly et al., 2021). Since its completion, the Karakoram Highway has experienced numerous natural disasters, including rockfalls, debris slides, debris flows, mudflows, dry powder flows, flash flooding from water and river gravels, foundation undermining due to abstraction, subsidence, and frost heaving (Kardon, Kennedy, & Dutton, 2020). The road surface is frequently damaged by freezing, floods, and the impact of rockfalls.

To comprehensively assess the hazards, we conducted a survey covering over 200 km from the Khunjerab Pass (the border between Pakistan and China) to Gilgit.

Both field mapping and gravimetric approaches were utilized to study landslides and debris flows.

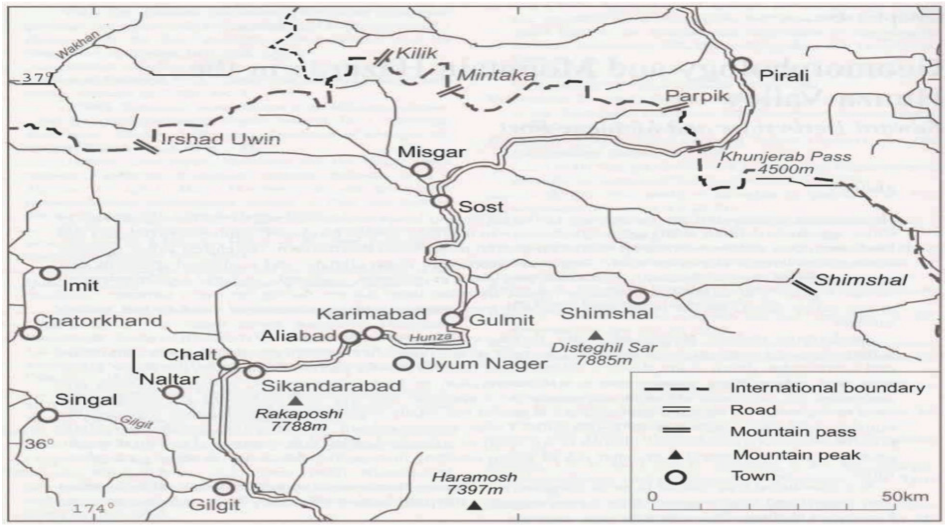

Figure 1. Selected locations in relation to the Karakoram Highway, northern Pakistan (Source: Derbyshire et al., 2001)

Figure 1. Picture shows the Attaabad landslide triggering situation (4th January 2010). (Source: from internet, photo by local)

The Karakoram Highway (KKH) faces significant threats from various natural disasters influenced by the geological features along its route (Kulsoom et al., 2023; Maqsoom et al., 2022). These hazards include large-scale meltwater streams from select glaciers and semi-permanent mass movements on steep cliffs of uncemented late Pleistocene till. The most significant risks come from talus fan sliding, alluvial, and mudflow fan progradation (Edward Derbyshire & Owen, 1990).

Landslides are primarily caused by environmental changes, with an increasing number resulting from extreme climatic events that devastate finances and human lives. The KKH is a crucial component of the Asian Highway Network, serving as a geopolitical bridge connecting China and Pakistan with the South Asian continent and acting as a geospatial link between Pakistan and China (Baghel & Nüsser, 2015; Khan, Shitao, & Khan, 2022).

The raised mountain topography, abundant loose material, and sudden heavy rainfall contribute to severe geological disasters, including rock collapses, glacier debris flows, landslides, debris creep, soil creep, and occasional avalanches (Walker & Shiels, 2012). Since 1987, around 115 rock avalanches have occurred due to extremely large rockslides or rock falls (Zimmer & Sitar, 2015). The massive earthquake that struck northern Pakistan in 2005 caused significant long-term damage to the KKH and triggered numerous landslides. In 2010, a massive landslip at Attaabad blocked the river, forming a barrier lake that extended over 20 km in length (Butt, Umar, & Qamar, 2013). This event submerged the road and caused severe traffic disruptions (see Figure 1).

It was determined that 150 glacier debris flow over the KKH caused bridge damage by 2011 (Zhao et al., 2019). As a result of all these tragedies, roads and the neighborhood suffer tremendous harm. Assessing KKH's susceptibility to geological disasters is essential for this reason. The current disaster assessment of the region, however, only concentrates on the investigation and evaluation of a single debris flow ditch or landslip, such as the investigation of surge-type glaciers and the activity degree evaluation of glacial debris flow, due to the vast extent and complex geological conditions in this region. Furthermore, there needs to be more regionally specific historical disaster data, making it difficult to do the disaster assessment.

Background

The region of the Karakoram Mountains in Pakistan's extreme north is hostile. The highest known rates of uplift sustain some of the highest relative relief on Earth, and the incredibly steep climate gradients (from glacial to hyper-arid) produce an environment that is characterized by extremes (Edward Derbyshire, Fort, & Owen, 2001). The presence of the biggest glaciers outside the polar regions, seasonal hydraulic action from strong precipitation events, quick snow and ice melting, and frequent earthquake shocks all contribute to the instability of the numerous thick accumulations of young, uncemented sediments and the long, steep slopes (Owen & Derbyshire, 1988). Regionally and locally, the landscape system is characterized by extremely high erosion rates. Numerous natural phenomena, such as huge rock avalanches (Hewitt, 1989), produce localized, high-magnitude, low-frequency events that are challenging to foresee and accurately predict. The area is lightly populated because there are few locations appropriate for human settlement and life. Even so, the history of the impact of such events on the human settlements, recorded from 1830 to the present (Kreutzmann, 2006), makes sober reading. The imposition, at the end of the 1970s, of a major engineering structure, the Karakoram Highway, on this dynamic terrain introduced into the Hunza Valley for the first time a source of human-induced geological hazards of a much higher order than before. This study is the first to provide a detailed (1 km spacing) factual statement of the relationship between terrain type, operative surface processes, and highway condition for the entire length of the highway in the Hunza Valley. In Gilgit-Baltistan, risks from geological and hydro-meteorological hazards seriously threaten people's lives and means of subsistence. There is a seismically active zone throughout the entire area (Edward Derbyshire et al., 2001).

The hydro-meteorological risks in these mountain valleys include landslides, rock falls, debris flows, snow or ice avalanches, glacial lake outburst floods (GLOFs), and flooding. Debris flows, floods, and earthquakes frequently cause havoc with daily life and set back local development. The 1858 Sarat Rock Avalanche with subsequent catastrophic lake outburst flood and the 1893 and 1905 Karambar Glacier Lake Outburst Floods, both of which occurred in Gilgit-Baltistan and destroyed numerous villages along the main rivers downstream, are a few past historic (catastrophic) events (Hussain, Sadiq, & Latif, 2010). These events occur in addition to the "normal" natural events that frequently occur and have a small geographic extent.

These natural events have a significant impact on the local populace. As more regions are used for agriculture, commerce, and housing that are vulnerable to natural disasters and unsuitable for any human activity, there is also an increase in physical vulnerability. Besides the population's exposure to natural threats, the socio-economic conditions in Gilgit-Baltistan and Chitral are unfavourable. Most households need more financial resources and employment possibilities. Their ability to manage the risks from many dangers is essentially non-existent. Additionally, according to IUCN Pakistan, the high population growth rate (5 to 6 children per family are still considered normal) results in a noticeably higher need for food, energy, and land. Indications of the negative impact of climate change on wildlife and natural disasters are a significant issue across the entire area (Bruce, 1994). People observe changes in snowfall (stronger events with subsequent avalanches), thunderstorm frequency, and the beginning of the hot and dry season earlier. The China-Pakistan Economic Corridor (CPEC), which links western China and northern Pakistan, includes the Karakoram Highway (KKH). It forms the intersection of the Indian and Eurasian plates, passing through the Himalayas, Karakoram, Hindu Kush Mountain ranges, and the Kohistan Island Arc (Edward Derbyshire et al., 2001). Arid to monsoon climate, fractured and worn rock masses, a variety of lithologies (igneous, metamorphic, and sedimentary), strong seismicity, deep gorges, high relief, and locally high rates of tectonic activity are all features of the region (Edward Derbyshire, 1996). The study region is a unique geohazard laboratory due to these circumstances. Numerous geohazards have threatened KKH's stability ever since it was built in 1979. The 840 km long (10 km buffer) Karakoram Highway (KKH), N35, which is situated in the Karakoram Mountains of the Himalayas, is the research area. The region has some of the world's tallest peaks (Rakaposhi: 7788 m) and highest reliefs (Hewitt, 1989). According to (Goudie, 1984), the steepest location on Earth is the research area, where the elevation decreases from 7788 to 2000 m over a horizontal distance of 10 km.

Glaciers and Climate Change

Climate change affects glaciers adversely. The Himalayas and adjacent areas of High Asia have recently been the subject of numerous reports of significant changes, most commonly the rapid retreat of glaciers. On a local, national, and global level, there is worry about the effects of various glacier risks and how reliable water resources are. Glaciers are dynamic, and as such, they significantly impact the hydrologic, geologic, and biological systems in the settings where they are found. Glaciers offer good indicators of local and global climate change due to their sensitive and dynamic reaction to changes in temperature and precipitation. A lengthy and labor-intensive process goes into glacier monitoring and analysis. Years may be needed to investigate the effects and alterations in a glacier and how glaciers respond to the projected climate scenario. To prepare and conduct more in-depth research, we must quickly gather the most data possible. Most of the rivers' sources are glacier meltwater and snowmelt. Climate change in the area is causing flash floods and other hydro-meteorological occurrences. The entire area comprises young, tertiary mountain ranges that are still tectonically active. The area has GLOFs, unstable steep slopes, debris flows, and land sliding.

However, it is becoming increasingly apparent that the region's glacial conditions and climate change adaptations are diverse. Glaciers play a significant role in the hydrologic cycle and impact the quantity, variability, and quality of runoff. To evaluate and forecast how glaciers may affect water supplies, a monitoring program is necessary to give the fundamental information. The glaciers serve as a water tower for freshwater supply and a data bank for studying quaternary climatic changes because they are still sensitive to earth temperature changes. Most glaciers are reportedly melting quickly across the globe. There have been numerous reports of "disappearing glaciers" throughout High Asia. The glaciers in this area have survived for many years, and recently, many of them in the Karakoram Himalaya have begun to thicken and advance. This not only goes against the general trend for Eurasian glaciers but also against what had been occurring to Karakoram glaciers. They, too, waned and receded for most of the 20th century. There is no doubt that the behavior of today is a uniquely localized response to climate change. Given the prevalent sorrow for the melting of the glaciers, it might sound encouraging, but that would also be false. Glaciers that are moving forward also pose risks.

In different Asian mountain regions, climate change has different effects. The situation in the Karakoram must reflect some circumstances. Three characteristics of the local environment seem crucial. The glaciers' sustenance and snowfall are discussed in the first two points. They fall somewhere in the middle between the larger Himalayas' summer accumulation (snowfall) glaciers and the Caucasus and European Alps to the west's winter accumulation glaciers, for example. Significant glacier retreat is noted in each of the latter. Second, in contrast to most other mountain ranges and these, the Karakoram has a far higher zone of maximum precipitation. It also lies totally inside the glacier accumulation zones. This relates to the third element, the extraordinary altitudes, and the elevation range of these ice formations.

High-mountain and polar locations have glaciers essential to their culture, environment, and landscape. They are a unique source of fresh water for domestic, industrial, and agricultural usage. They are also a significant source of revenue for the hydroelectric industry and tourists. The pace of melting of glaciers, which is the best indicator of climate change due to the rapid increase in world temperatures. Since most glaciers' ice is on the verge of melting, they respond to temperature changes very quickly, and as a result, they offer some of the most direct proof that climate change is still happening. Since they are still susceptible to fluctuations in the world temperature, the glaciers serve as a water tower for the provision of freshwater as well as a data bank for studying quaternary climate changes. As a result of shifting climatic circumstances in Pakistan's glaciated region, glacial lake outburst floods (GLOFs) pose a significant risk to the people that live downstream. Because of unstable moraine "dams," the glacial lakes that are held back by them-known as "Glacial Lake Outburst Floods"—may unexpectedly burst. This is because the glacial lakes are held back by moraines or the ice core of retreating glaciers. Between Gilgit and Sost, on both sides of the Hunza River, are remains of a catastrophic rockslide, whose original volume probably exceeds 500 x 106 m^3.

Environmental Settings

The Karakoram Highway (KKH), completed in 1979, is the only overland route connecting the People's Republic of China with the Islamic Republic of Pakistan. The original motives for this ambitious project were both strategic and economic. The route runs from the Pakistan lowlands below 1000 meters, across the Khunjerab Pass (about 4500 meters), into the Chinese Autonomous Region of Xinjiang. The upper portion of the KKH crosses one of the most dynamic mountain ranges on Earth by following the valley of the Hunza and Khunjerab rivers (E Derbyshire & Miller, 1981). It traverses various morphoclimatic zones, ranging from highly arid valley floors to glacial and periglacial conditions on the mountain peaks such as Rakaposhi (7821 m). The Karakoram Mountains lie immediately to the north of two major geological structures, the Indus (or Shayok) and northern sutures, that mark the closing of the Tethys and the collision of the Indian and Asian continental plates (Fig. 2). From about 50 Ma ago to the present day, mountain building processes have continued to stimulate growth of the Himalaya to the south and the Karakoram Mountains to the north (Searle, 1991). In the western Himalayas, the uplift rate has been estimated to be about 1 cm/year (Zeitler, 1985), ten times the average rate for the Himalayan Range. This, together with rapid glacial and fluvial incision, has resulted in deeply incised valleys and some vast valley fills that are relatively easily examined in field sections. In the Hunza and Khunjerab valleys, the main structural grain trends WNW-ESE with the major formations mimicking this trend (Fig. 3). For most of its length, the KKH, therefore, runs approximately perpendicular to both the structural and lithological trends. The KKH crosses four major geological terrains (Searle, 1991). The Karakoram Sedimentary Series (in the north), the Karakoram Batholith, the Karakoram Metamorphic Complex; and (in the south) the Chalt Green Schist Zone. The Karakoram Sedimentary Series comprises highly jointed and locally deeply weathered Palaeozoic and Mesozoic slates, limestones, and dolomites. Cryogenic weathering dominates these lithologies to produce cliffs surmounted by long scree slopes (Edward Derbyshire et al., 2001). The Karakoram Batholith (Tertiary in age) consists mainly of granodiorite but includes diorite and granite. The batholith is deeply incised to form steep cliffs that exhibit impressive cavernous weathering forms (Whalley, 1984). Salt crystal growth and cryogenic processes dominate the weathering throughout this zone. The Karakoram Metamorphic Complex includes gneiss, schist marbles, phyllites, pelite and amphibolite's, greenschist, agglomerates, and tuffs (Windley, 1983).

The Karakoram Highway traverses one of the Earth's most quickly climbing mountain ranges. It is in extremely high geodynamic activity due to a combination of earthquakes, glacial erosion, river incision, periglacial action, and an unpredictably significant input of monsoonal rains. Since it was finished, the Karakoram Highway has seen damage and interruption from rockfall, sliding rock and debris, debris flow, mudflow, dry powder flow, flash flooding by water and stream gravels, basement undermining by abstraction, subsidence, and frost heaving (Kron et al., 2021). The road surface frequently sustains damage from rockfall impact, flooding, and frost breaking. A rigorous hazard study was carried out over a more than 200 km radius from the Khunjerab Pass (Pak-China boarder) to Gilgit. The debris flows and landslides were evaluated using field mapping and gravimetric techniques. The largest significant risks include meltwater streams from some massive glaciers and semi-continuous mass movements on steepened cliffs of uncemented late-Pleistocene till. Talus fan sliding and alluvial and mudflow fan progradation are the most frequent risks (Edward Derbyshire et al., 2001).

Problem Statement

Gilgit-Baltistan is in one of the snow-packed zones of the world, including Hindukush, Karakoram, and the Himalayas. Due to an average rise in the world's temperature and the active zone of the MKT (Main Karakoram Thrust), natural hazards like flash floods, glacial lake outburst floods (GLOFs), and landslides have recently become more frequent and intense in the HKH region. The glaciers in Pakistan are thinning off at a rate of 40–60 m every ten years due to the rapidly changing climate. The amount of water in the glacier lakes is rising because of these glaciers' melting. The Gilgit-Baltistan and Chitral basins are also dealing with the effects of climate change in the form of rapid glacier mass melting, lake expansion and lake creation, which poses a risk for glacier Lake Outburst Floods to the communities below. These hazards have severely affected the region for centuries, and damage was recorded in terms of lives, property, and other infrastructures. Some examples the past floods and GLOFs are the 1835 floods in Shyok River, the 1905 GLOFs of Karumber and Shimshal Rivers and the recent records flashflood of July-August of 2010 and July 2020. Huge damages were recorded throughout Pakistan. In the Hunza and Gilgit River basins of the Karakoram and Hindu Raj Ranges, recent investigations have found at least 79 rockslide-rock avalanche episodes (Fig. 1). At high elevation in glacier basins, several have happened in the previous 150 years, and two episodes have happened in the last 15 years. Most instances, however, were rebuilt from sediments that were essentially old. They were all late Quaternary post-glacial events since they almost all fell onto the bottoms of ice-free stream valleys. They were located using sediment samples and field research, with the aid of satellite imaging analysis. Rockslide-rock avalanches (Telssturz-Sturzstrom5 events) derive from sudden rock wall failure or collapses involving millions of cubic meters of bedrock (Hewitt, 2001). Typically, a steep slope of several hundred meters will result in the rock being thoroughly fractured, crushed, and ground into a fine powder. As a result, dry rubble runs out quickly.

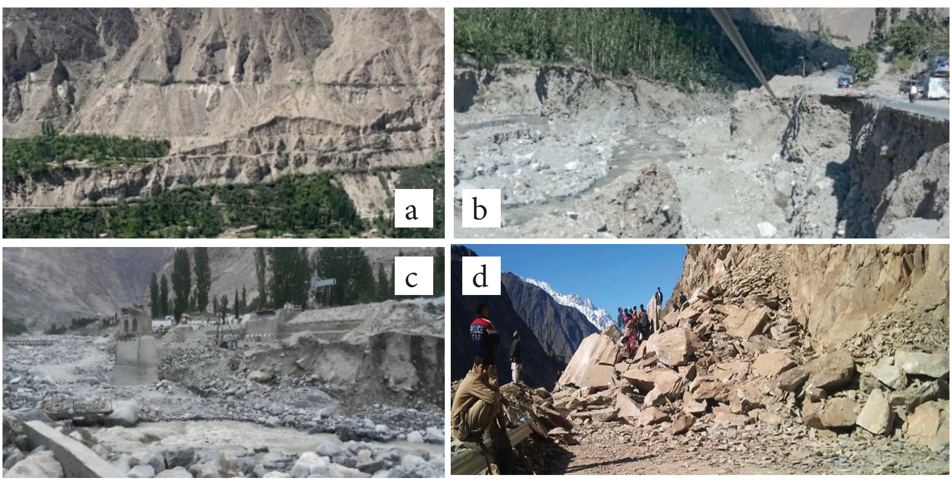

Figure 2. The picture shows **a).** Landslide near Nasirabad Hunza **b).** The Shisper Glacier Lake Outburst Flood (GLOF 7th May 2022) eroded KKH in Hassanabad Valley. (Source: a, b, and c by Dr. Garee Khan, d. Internet source).

Study Area

The 300-km Karakoram Highway buffer defines this study region. It travels from Gilgit to the Khunjerab Pass, close to the Chinese border. It is situated in the western portion of the India-Asia collision-induced Karakoram-Himalayan orogenic belt. Mountain glaciers are a significant part of the ecology around the roadway because they cause significant rock avalanches and glacial debris flows. The KKH's topography, which ranges in elevation from 1280 to 6961 m, is characterized by deep valleys and rough mountains. Deep, narrow river valleys result from strong tectonic processes and quick uplift, which provide dynamic conditions that encourage the development of geological disasters. As a result, the KKH is frequently affected by geological disasters like mudslides, landslides, and flash floods that cause significant damage to the KKH.

Objectives

The proposed study will assess the risks and vulnerabilities of the natural hazards along the CPEC route. The main objectives of the program are as below.

- To indicate and assess the degree of risk and mitigate hazards.
- To increase the public institutions' technical and human capacity to comprehend and respond to the urgent risk posed by the different mountain hazards along the KKH.
- Reducing Risks and Vulnerabilities from natural hazards.
- To help the local, vulnerable communities in Gilgit-Baltistan better comprehend and adapt to mountain dangers to cope with the increasing strain from climate change.

Benefits

The expected benefits of the program are.

- Capacity building of the local community and relevant stakeholders
- Reduction of material and human losses due to mountain hazards
- Safety of agricultural land, forestry, livestock, and biodiversity
- Enhance the response capacity of the local community.
- Developed the preparedness level of the community and stakeholders.
- Reduction of risk both through the physical and non-physical mitigation
- Adaptation of the community to the existing risks
- Ultimate sustainable development

Policy Framework and Guidelines to Address Mountain Hazards Risk

An interagency working group will be established to integrate climate change risk management considerations into future laws and current disaster management policy frameworks. To add mountain hazards and climate risk variables, update the National Disaster Risk Management Plan and then submit it for NDMA approval. At the district and neighborhood levels, create and institutionalize comprehensive mountain hazard risk management standards, especially for individuals at risk from mountain hazards.

Strengthening Knowledge and Information about Risks

Interaction with the Global and Regional Research Centers Working on Mountain Hazards Issues

To assess the state of knowledge on the consequences of glacial melt and related flooding patterns in the Himalaya-Hindukush region, establish cooperative relationships between national and local disaster management agencies and specialized research institutions, including NDMA, NIDM, and GBDMA. The organizations that KIU may like to work closely with.

1. National Disaster Management Authority (NDMA)
2. Pakistan Metrological Department (PMD)
3. Global Change Impact Study Centre
4. Pakistan Council for Research on Water Resources
5. Institute of Geographical Information System
6. ICIMOD

Hazard & Risk Mapping of CPEC Route

The first step would be obtaining information about the CPEC route using remote sensing and GIS, then listing the risk categories. Community members and other stakeholders will be consulted to determine the vulnerabilities in areas at high risk for disasters and to determine the technological, natural, human, and social resources that are already available. Creation of comprehensive vulnerability and risk maps (fusing livelihood sensitivity and risk exposure).

Community-Based GLOF Risk Management in Vulnerable Mountain Valleys

Early Warning System

The existing flood early warning systems will be installed in the target locations along KKH to continuously transmit flash warning signals. Threat detection (sensor), warning stations, and relay stations are intended to be included in the EWS design.

i. GLOF watch advisories published in print and electronic media by Pakistan Metrological Department (PMD) for communities in danger.

ii. Establishment of an SMS message system to send alerts to government agencies, neighborhood NGOs, and community-based organizations (CBOs).

iii. Establishing a central voice response system will allow consumers to access flood risk information by phone or mobile call whenever they choose day or night.

iv. Community-level, real-time mock drills that imitate a GLOF disaster and test the EWS's functionality.

Selected local community and NGO members will receive training in the calibration, use, and maintenance of the sensor equipment that PMD has deployed at the target sites.

Community-Based Mitigation

Potential flood threats can be reduced using a variety of methods. The reduction of the likelihood of a lake flood is the main goal. Combining these methods with EWS-based procedures downstream is crucial because coordinated actions to safeguard life and property in the downstream area must also be performed. The most frequent structural mitigation strategies aim to lessen the lake's water level. The most efficient mitigation strategy is to reduce the lake's water level, which should lower both the projected peak surge discharge and the hydrostatic pressure on the moraine dam. Various approaches can be employed singly or in combination to accomplish this.1. Controlled breaching of the moraine dam

i. Building a building to restrict outlets.

ii. Pumping or syphoning water out of the lake.

iii. Tunneling under an ice dam or through the moraine barrier.

Community-Based Hazards Risk Assessment, Monitoring, and Early Warning System

- Create a network of local government and community organizations for early warning communications, using various communication channels such as the phone, cell phone, and SMS.
- Create a centralized early warning and response center that continuously receives and relays alerts over the phone.
- Develop and build the technical elements of a successful EWS, including hazard sensors, relay stations, warning signal installations, and a low-tech backup system to reduce technological hazards.
- At least one real-time GLOF simulated drill is carried out annually to check the effectiveness of the EWS and make any necessary adjustments. The use and care of it are covered in staff training.

Capacity Building

Training Awareness Sessions

- Inform end users/farmers at the local level in Gilgit-Baltistan and Chitral about the Pakistan Meteorological Department's climatic advisories.
- Arrange for district and local level authorities in Gilgit-Baltistan and Chitral to attend workshops and seminars on GLOF readiness and risk mitigation strategies.
- Engage in awareness-raising initiatives for the communities of Chitral and Gilgit-Baltistan, such as publishing newspaper articles, radio programs, localized posters and brochures, and regional consultations.
- Include awareness-raising initiatives for women and vulnerable populations (such as children, the elderly, and people with disabilities) in all communication efforts to lessen disproportionate vulnerabilities and guarantee the measures.

Identification of Safer Areas

- Hazard and risk maps already developed will be used to check the prevalent hazards downstream and prioritize the safer areas.
- Safer areas will be identified by considering all the hazards and risks in the surrounding areas.
- Safe havens will be identified within the safer zones, which will be used in case of any disaster to accommodate the affected community.

Safe Exit Routes

Through community participation using hazard and risk maps of the target villages, exit routes will be identified and marked on the map for safer evacuation in case of any disaster, so the risk of damage to lives can be reduced.

Mitigation Measures Downstream

In addition to the mitigation at the glacier and lake, downstream mitigation for the community is imperative to reduce the risk of flood in the case of GLOF. Several techniques and methods are used to minimize the existing threat, some of which are as follows.

Tunneling

Tunnels can be constructed to keep the road safe from rockfall and debris flow.

Retaining Walls

Due to road construction slope could be unstable, and there is the probability of slope failure and rock slump on the road. To avoid such hazards retaining walls can be constructed.

Channelization

Due to several flood events along the specific stream or river, the aggradation of the river/stream occurs due to a sudden decrease in the gradient. Excavation of the debris material can be done to increase the capacity of the stream to accommodate both massive and regular floods to reduce the risk of overflowing towards the settlements.

Check Dams

Depending on the ground situation and feasibility, several options can be utilized to reduce the risks. Check dams are one of the methods to check the debris material brought by the GLOFs or floods.

Gabion Wall/Diversion Spurs

Gabion walls are used to fall where there is a sharp turning of the stream change of overtopping towards the settlements. In the case of meandering river diversion, spurs are feasible to reduce erosion or to cut by the flood.

Suggested Citation

Baig, S.S., Khan, G, Alam., M. (2023). Geological Hazards along the CPEC route from Gilgit to Khunjerab. In *Silk Route Revisited: Essays and Perspectives on the China-Pakistan Economic Corridor and Beyond* (pp.212-227). CSC-KIU.

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