# Debris flow mitigation in Chitral Region, Pakistan

**Z. Uddin, T. Zaman, M. Anjum, S. Uddin, N. Uddin**

*Branch of the Aga Khan Agency for Habitat in Pakistan, Islamabad, Pakistan, zia.uddin@akdn.org, tahir.zaman@akdn.org, muhammad.anjum@akdn.org, salahuddin@akdn.org, nasiruddin.shah@akdn.org*

**Abstract.** Most of the villages in the Hindukush region are settled on alluvial fan and riverbed. The catchment of the alluvial fan is composed of high peak mountains that are covered with glaciers and snow. The glaciers and snow are the main sources of water for drinking and agriculture purposes. Debris flows is a major hazard in the Hindukush region where they repeatedly result in disaster. In 2015 debris flow and flash flood caused 30 casualties in the Chitral region besides infrastructure damage. Debris flow events occur due to the rapid melting of glacier/snow and intense rainstorm, instability of steep slopes, and unconsolidated material overlying bedrocks. Through Hazard Vulnerability and Risk Assessment, (HVRA) maps of different villages are developed. Each hazard is further classified based on intensity and frequency. Based on risk and feasibility mitigation is recommended. Two types of mitigation are practiced passive and active mitigation. Passive mitigation is carried out by sharing of hazards and Risk maps with Government and other stakeholders for land use management. Based on hazard maps awareness seminars in villages are conducted and people are educated about prevailing geohazards. Safe routes are also identified and through mock drill communities are prepared to do the evacuation. Active mitigation is focused on the reduction of hazard levels by the construction of protection walls, channelization, and check dams. After completion of mitigation projects, the risk has been reduced according to HVRA maps. Post-disaster analysis of mitigation structures is necessary to evaluate the effectiveness and sustainability of the designs to improve future projects.

***Key words:*** *debris flow, mitigation, alluvial fan, protection wall, hazard*

**Cite this article:** Uddin Z., Zaman T., Anjum M., Uddin S., Uddin N. Debris flow mitigation in Chitral Region, Pakistan. In: Chernomorets S.S., Viskhadzhieva K.S. (eds.) Debris Flows: Disasters, Risk, Forecast, Protection. Proceedings of the 6th International Conference (Dushanbe–Khorog, Tajikistan). Volume 1. Dushanbe: “Promotion” LLC, 2020, p. 282–289.

# Мероприятия по смягчению последствий селевых потоков в округе Читрал (Пакистан)

**З. Уддин, Т. Заман, М. Анджум, С. Уддин, Н. Уддин**

*Филиал Агентства Ага Хана по Хабитат в Пакистане, Исламабад, Пакистан, zia.uddin@akdn.org, tahir.zaman@akdn.org, muhammad.anjum@akdn.org, salahuddin@akdn.org, nasiruddin.shah@akdn.org*

**Аннотация.** Большинство сел в Гиндукуше расположены на аллювиальных конусах и в днищах речных долин. Водосборные бассейны, заканчивающиеся аллювиальными конусами, окружены высокими горными хребтами, покрытыми ледниками и снежниками. Ледники и снежники являются основными источниками воды для питьевых и сельскохозяйственных целей. Большую опасность для горного региона Гиндукуша представляют селевые потоки, где они неоднократно приводили к катастрофическим последствиям. В 2015 г. селевые потоки и ливневые паводки, помимо ущерба, нанесенного инфраструктуре, привели к 30 жертвам среди населения в округе Читрал. Селевые потоки происходят из-за быстрого таяния ледников/снега и интенсивных ливней, нестабильности крутых склонов и налтичия больших объемов рыхлого материала, накопившегося поверх коренных пород. По результатам оценки уязвимости и риска (HVRA) составляются карты различных населенных пунктов. На основе этой оценки рекомендуются мероприятия по снижению риска. Практикуются два типа мероприятий по смягчению последствий: пассивные и активные. Пассивное смягчение осуществляется путем обмена картами опасностей и рисков с правительством и другими заинтересованными сторонами для разработки мероприятий по управлению землепользованием. На основе карт опасности проводятся семинары по повышению информированности населения о преобладающих георисках. Также определяются безопасные маршруты, и с помощью тренировочных учений население готовится к эвакуации. Активные меры по смягчению последствий сосредоточены на снижении уровня опасности путем строительства защитных стенок, создания дополнительных русел и противоселевых дамб. После завершения проектов по снижению риска, согласно созданным картам, риск снижается. Для оценки эффективности разработанных мер и с целью улучшения будущих проектов необходима проводить анализ эффективности этих мер после прохождения стихийных бедствий.

***Ключевые слова:*** *селевой поток, мероприятия по смягчению последствий, аллювиальный конус, защитные стенки, опасность*

**Ссылка для цитирования:** Уддин З., Заман Т., Анджум М., Уддин С., Уддин Н. Мероприятия по смягчению последствий селевых потоков в округе Читрал (Пакистан). В сб.: Селевые потоки: катастрофы, риск, прогноз, защита. Труды 6-й Международной конференции (Душанбе–Хорог, Таджикистан). Том 1. – Отв. ред. С.С. Черноморец, К.С. Висхаджиева. – Душанбе: ООО «Промоушн», 2020, с. 282–289.

## Introduction

In the north of Pakistan there lies a deep river traversed valley Chitral located in the eastern Hindukush Ranges at the south-western part of the Pamir Syntaxis [*Haneef, 2010*]. The district Chitral overlays an area of_15,000 km$^2$ in mountainous terrain with an elevation range from 1000 m to 7700 m above sea level (a.s.l.) [*Saeed et al., 2010*]. The river of Chitral crisscrosses the district as a primarily U-shaped valley molded in response to Late Quaternary ice-age glaciations [*Saeed et al., 2010*]. The location of the understudied village is in Chitral named Awi Shoghore and georeferenced as 36.00833N, 71.75833E. The village under multiple hazards but debris flow is the most prominent. In July 2015 debris flow completely damaged 2 households and partially damaged 4 households besides cultivated lands, and forests. In the course of Quaternary, valley-fill sediments of great width have been deposited by glacial, fluvial, eolian, and mass-movement processes and the fluvial incision eroded these sediments and formed terraces. Their development was controlled by tectonic and climatic influences, and therefore they record information about the Quaternary landscape evolution and glaciations [*Kamp, 2004*]. Climate change effects on the glacier bearing mountains and increased climate variability are already affecting water accessibility, and extreme weather is causing flash floods, landslides, and debris flow [*Arabinda Mishra, 2019*].

The most familiar geomorphic trait of the Chitral region is steep slopes associated with high-relief mountains, which fuse into extensive relatively even floodplains. The dense network of the tributary system covers these slopes. They drop sediments on go into valley floors developing a range of tributary-junction landforms including debris cones, debris fans, and alluvial fans [*Tahirkheli, 2013*]. In a region, where plane land for settlement and cultivation is rare, fane terraces are used, and in some cases, these are the only available site for habitation. Developments in irrigation technology and road building has enabled the increasing population to a spread of settlements and cropland on these alluvial fans. Such areas are prone to glacial-lake outbursts that cause flooding of the fans, damaging life, property, and crops [*Tahirkheli, 2013*]. The Hazards that occurs on the fan surfaces are mainly hydrogeomorphic and are categorized as floods and debris flow based on sediment/water ratio during their carriage and the floods have water content with sediments of 40%.

In comparison, debris flows have 70–90% sediment concentration by weight, forming a heterogeneous admixture and typically forms marginal levees and terminal lobes when deposited [*Tahirkheli*, *2013*].

This paper will focus on the dynamics of debris-flow hazards for alluvial fans with unstable toe bassline deposition, with sediment concentration above 40%, which includes debris flow and debris flood [*Tahirkheli, 2013*]. The rise in debris flow hazard increases in human-environment interaction and the number of people and asset values exposed to hazards. Vulnerability measurement and assessment are recognized as key components for reducing losses from disasters and facilitating a culture of disaster resilience [*Rasler*, *2018*]. To minimize the vulnerability of the area, hazard vulnerability and risk assessment carried out and based on assessment physical mitigation had been done which reduced the risk from high intensity to low, of the area [*Rasler*, *2018*].

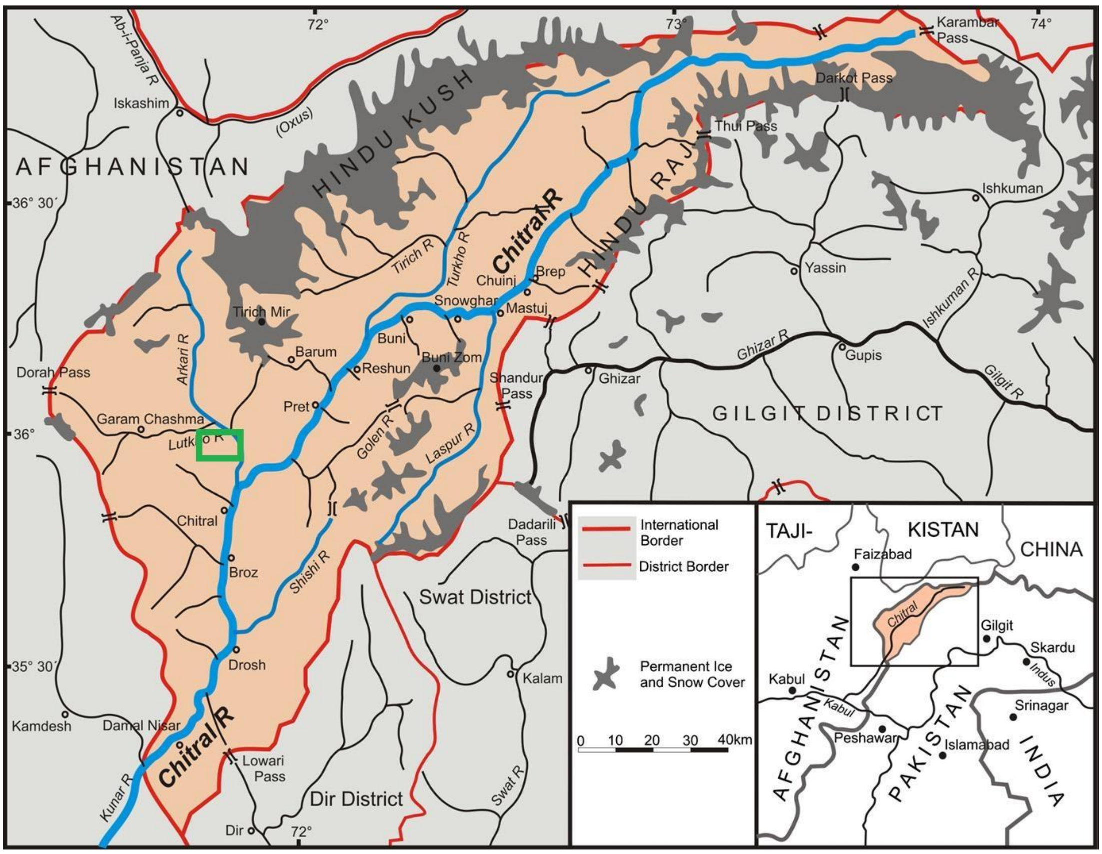


Fig. 10. Location Map of District Chitral, studied area is identified as a green square [*Haneef, 2010*]

## Brief Review of the Problem

The design and implementation of active mitigation measures are vital to reduce the impact of debris-flow activity and to protect inhabitants living downstream. The main problem in active mitigation is the geomorphology of the site and the design. The protection wall has been considered as the most suitable active mitigation structure for alluvial fan geomorphology. The research focuses on the impact of active mitigation on the inhabitants living in debris flow risk areas.

## Methods

Since hazards occur at the juncture of socio-ecological systems, reducing hazard loss requires the all-inclusive assessment of risk that considers combined distinctions of the physical, built, and social environments of a place. Hence, risk assessment, and ultimately vulnerability reduction, are processes that require multidisciplinary knowledge of various coupled physical and social processes to calculate the increasing level of risk posed by hazards [*Aksha et al., 2019*].

Risk assessment itself is a methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.

Risk assessments (and associated risk mapping) include a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process.

The methodology of research is based upon hazard risk vulnerability assessment of debris flow and the followed physical mitigative structures. The applicable mitigative design can minimize the effect of debris-flow intensity. the indication of its potential for destruction and is expressed as a function of the intensity and the return period. Its values will be used to weight the exposure in the risk calculation and should be relative values. The significance allows us to explicitly give more importance to frequent and/or high-intensity hazards in the risk calculation.

The location, design, and potential to resist the debris flow of the mitigative structure contribute to low the intensity of the debris flow [*Aksha et al., 2019*].

## Data

To Mitigate the debris flow risk AKAH Pakistan initiated a project to reduce the risk. The initiated project encompasses active mitigation. In active mitigation, the protection wall model has been used to lessen the intensity of debris flow. The household data and infrastructure data acquired from the HVRA database. The catchment of the debris flow in Awi is barren regolith encompasses an area of 35.92 km². The slope angle of the gorge is 5 to 7-degree steep to facilitate the debris velocity. To prevent the high risk of debris flow protective wall of 103 feet in length and 10 feet high from natural surface level has been built on the convex portion of the gorge.

Fig. 11. Cross-sectional view of protection wall along the gorge at the convex portion of the meandering stream

Fig. 12. Side view of the protection wall

## Analysis

The analysis based on the risk index of the village before and after the active mitigation The process of risk index described here leads to the calculation of two risk indices.

- Risk index (activity zone) better depicts the risk of infrastructure and economic activities, therefore the activity zone exposure is the physical exposure of the village to natural hazard
  *Risk Index(Activity Zone) =Exposure e(Area)*Vulnerability*

- Risk index (living zone) better depicts the risk of loss of life and injuries, therefore the living zone exposure is the percentage of a village population at-risk
  *Risk Index(Living Zone) =Exposure (Population)*Vulnerability*

For prioritization purposes, it might be required to summarize the risk index (activity zone) and the risk index (living zone) into a single risk index (village). Given that the living zone better depicts the location of people while the activity zone better depicts the location of activities and infrastructure, and given the relative importance of life lost compared to economic loss and infrastructure damage, it is accepted that the risk index (living zone) will be given a heavier weight. In addition, the population parameter of living zones is taken into account as by simple averaging of living zones risk index the final village risk can be misleading. Thus, the final calculation formula for village risk index is expressed as follow:

$$\mathbf{RiskIndex(Village)} = 0.8 * \left(\sum_{i=0}^{N} (\mathbf{RiskIndex(LivingZone_i)} * \mathbf{CalibrationIndex_i}) / N\right) + 0.2 * \mathbf{RiskIndex(ActivityZone)}$$

$$Calibration\ Index_i = Population(Living\ Zone_i) \,/\, \left(\sum_{i=0}^{N} (Population(LivingZone_i)\,/N\right)$$

where

– *CalibrationIndex* is a derived index to calibrate initial living zone risk index based on population factor;
– *N* is total number of living zones of an activity zone.

*0*.8 & 0.2 indicates 80% & 20% weight given to risk of living & activity zone respectively [*HVRA, 4 October 2014*].

Following the formula of risk index is calculated through Arc GIS has and the results are as follows [*HVRA, 4 October 2014*].

*Various Indices Pre Mitigation*

Table 7. The exposure, susceptibility, coping capacity, adaptive capacity, vulnerability, and risk in the pre mitigation scenario

| Hazard | Exposure | Susceptibility | Coping Capacity | Adaptive Capacity | Vulnerability | Risk |
|---|---|---|---|---|---|---|
| Avalanches | 0.0042 | 0.45 | 0.66 | 0.7 | 0.36 | 0.0015 |
| Bank Erosion | 0.0031 | | 0.77 | | 0.33 | 0.001 |
| Debris Flow | 0.2456 | | 0.66 | | 0.36 | 0.0889 |
| Earthquake | 0.149 | | 0.68 | | 0.36 | 0.0538 |
| Flood | 0.0168 | | 0.66 | | 0.36 | 0.0061 |
| Rockfall | 0.1259 | | 0.74 | | 0.34 | 0.0426 |
| **Multi-Hazard** | **0.5446** | **0.45** | **0.64** | **0.7** | **0.37** | **0.2005** |

*Various Indices Post Mitigation*

Table 8. Post mitigation indices

| Hazard | Exposure | Susceptibility | Coping Capacity | Adaptive Capacity | Vulnerability | Risk |
|---|---|---|---|---|---|---|
| Avalanches | 0.0043 | 0.32 | 0.7 | 0.74 | 0.3 | 0.0013 |
| Bank Erosion | 0.0033 | | 0.83 | | 0.25 | 0.0008 |
| Debris Flow | 0.1976 | | 0.7 | | 0.3 | 0.0579 |
| Earthquake | 1 | | 0.73 | | 0.29 | 0.2869 |
| Flood | 0.0157 | | 0.7 | | 0.3 | 0.0046 |
| Rockfall | 0.1278 | | 0.79 | | 0.27 | 0.0342 |
| **Multi-Hazard** | **1.3487** | **0.32** | **0.69** | **0.74** | **0.3** | **0.4029** |

The various indices illustrate the difference between the pre and post risk index of the village. The exposure difference is 0.17304 has been reduced due to active mitigation. the susceptibility has been also reduced from 0.45 to 0.32. the coping capacity and adaptive capacity has been increased from 0.66 and 0.7 to 0.7 to 0.74, respectively. Thus, the vulnerability of the habitat also condensed from 0.36 to 0.3. Hence the scenario changed the risk index of the village from 0.0889 to 0.0579 with a difference of 0.31 in response to debris flow mitigation.

Table 9. Impact of mitigation on the village Awi Shoghore

| | **Household** | | | **Population** | | | **Infrastructure** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **High** | **Medium** | **Low** | **High** | **Medium** | **Low** | **High** | **Medium** | **Low** |
| Before | 11 | 18 | 37 | 70 | 111 | 251 | Helispot, Hotel, Mosque, Water tank | Bank, School, Jamat Khana | Wildlife office, AKHC, AKHC Staff house |
| After | 0 | 30 | 37 | 0 | 202 | 251 | NA | Bank, School, Jamat Khana, Water Tank, Mosque | AKHC, AKHC Staff house, Wildlife Office |

The Table 3 illustrates the effect of active mitigation measures ensured the positive changes in the villages. After the mitigation, the 11 households in high risk moved to medium and low vulnerable areas. The infrastructure in high risk displaced to medium and medium to low consequently.

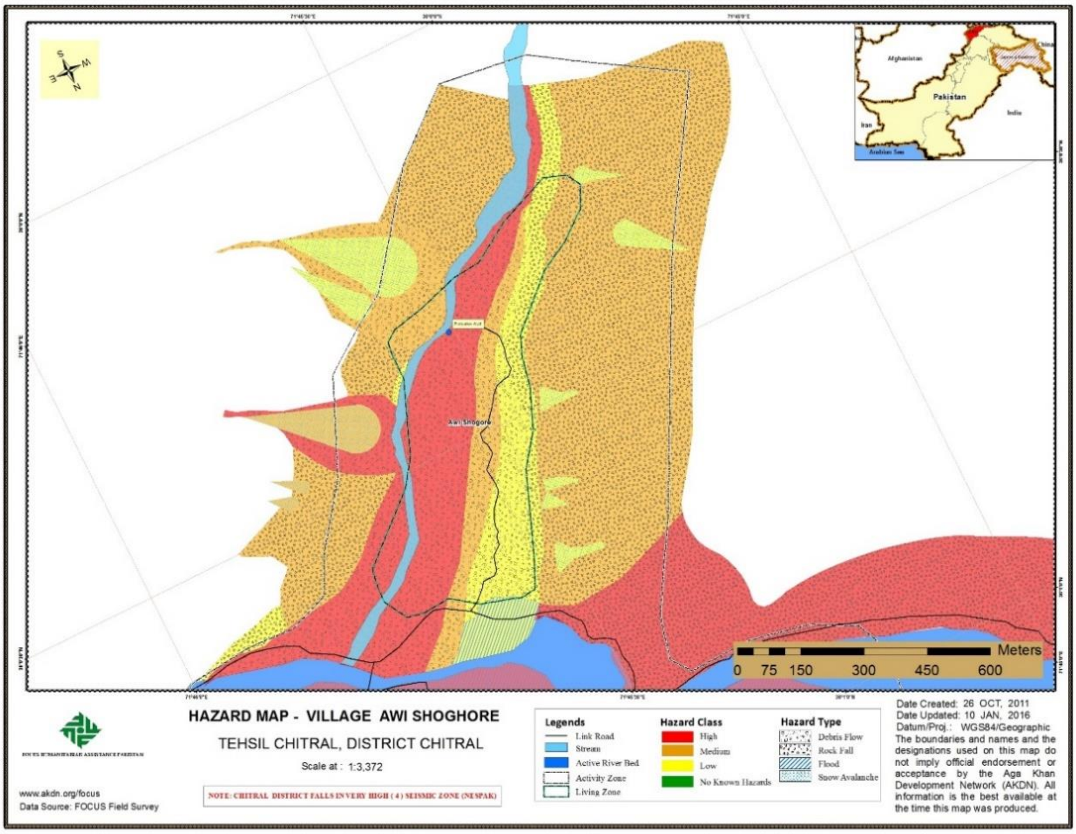


Fig. 13. Hazard map of the village developed before mitigation

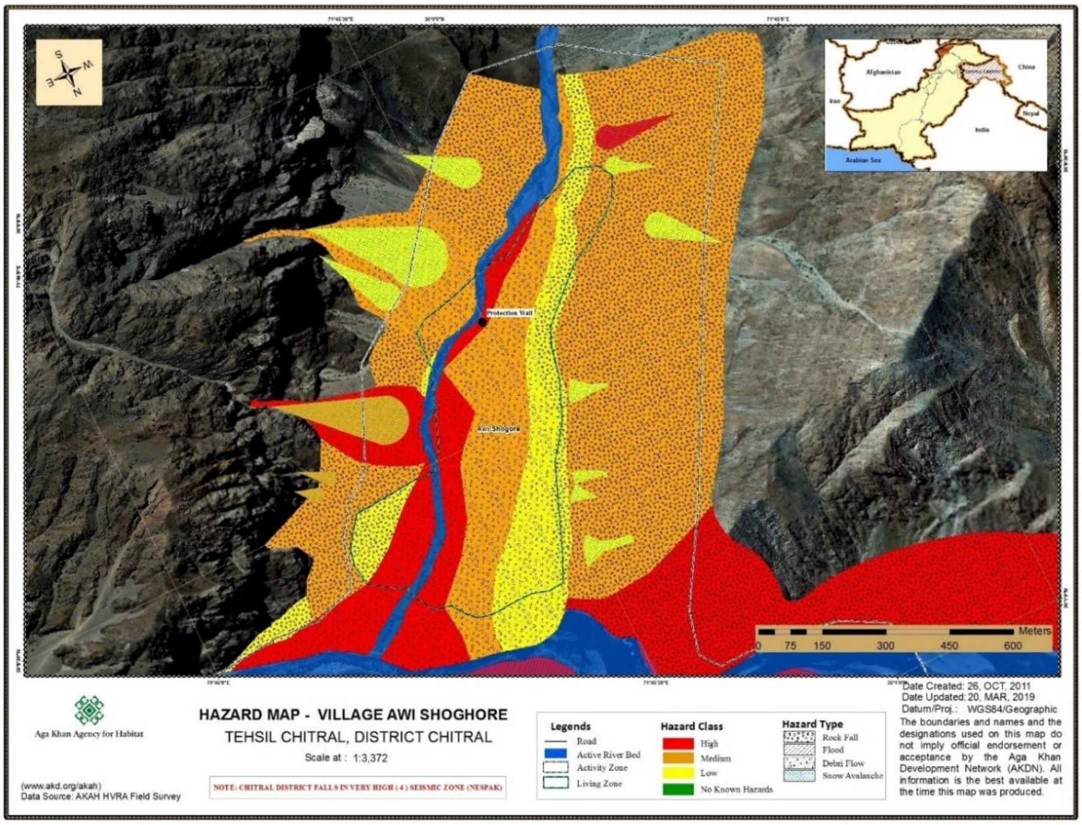


Fig. 14. Hazard map of the village after completion of the mitigation project. The map illustrates that due to mitigation the high hazard class has been shifted towards the gorge

## Conclusion

Natural hazards are the most prominent factor that affects the habitat in the northern areas of Pakistan. Although all hazards leave their mark on the community, but the debris flow is the most disastrous. Debris flow will affect the community if not mitigated properly. Due to climate change, the monsoon causes flash floods even in the Upper parts of the Chitral region. In the village, Awi Shoghore a small step has been taken to prevent the overflow of debris at critical points. Post-disaster analysis of mitigation structure is helpful to evaluate the effectiveness and sustainability of design. As both the precautionary and preventable measures were taken then the risk index of the village has been reduced.

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