Debris Flow Pilot Risk Management – a case from Sherqilla in Hindukush Region of Gilgit-Baltistan, Pakistan

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Abstract. Debris flow is considered one of the most devastating natural hazards in the Himalayan Karakorum and Hindu-Kush mountain ranges. Pakistan is 5th in the list of most vulnerable countries in terms of climate change, and signs are evident in terms of frequent and high intensity climate hazards. The northern part of Pakistan including Ghizer district of Gilgit-Baltistan (GB) is highly vulnerable to debris flow hazard. Historical record suggests that most debris flows occurred during June to mid-August due to heavy rains around the monsoon season and during April-May due to snow melting. A high magnitude debris flow event occurred on 3rd April 2016 due to rapid and intensive rain in short period, never experienced before in recent history of GB. This event totally washed-out 20 houses and displaced people to live in makeshift tents and with host families. Simultaneously similar events on 3rd April occurred in other two villages namely Silpi and Oshikhundass within the same region and several houses damaged. These specific events are extreme with debris travelling far and wide and any future events will results be disastrous with new habitation coming up. Aga Khan Agency for Habitat (AKAH) undertook multiple risk mitigation measures such as channelization and piloted community-based early warning system.

Key words: *Karakorum, Hindu Kush, climate change, erratic rainfall, early warning system, debris flow, mitigation*

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Пилотный проект по управлению рисками селевых потоков на примере селения Шеркилла в горах Гиндукуша (Гилгит-Балтистан, Пакистан)

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Аннотация. Селевые потоки – одно из самых разрушительных стихийных бедствий в горах Гиндукуша, Гималаев и Каракорума. Пакистан занимает 5-е место в списке наиболее уязвимых к изменениям климата стран, и доказательство этого – высокая частота и интенсивность стихийных бедствий, связанных с этими изменениями. Северная часть Пакистана, включая округ Гхизер (Гилгит-Балтистан), весьма уязвима в отношении опасности схода селевых потоков. Исторические данные свидетельствуют о том, что большинство селевых потоков происходило в период с начала июня по середину августа вследствие обильных дождей, выпадающих в сезон муссонов, и в период с апреля по май из-за таяния снега. Масштабный по объему и своим последствиям селевой поток сошел 3 апреля 2016 г. Он был связан с выпадением большого количества осадков за короткий период времени, чего еще ни разу не наблюдалось в новейшей истории Гилгит-Балтистана. Это событие привело к полному разрушению 20 домов и вынудило людей переселиться во временный палаточный лагерь и в дома к другим семьям. Одновременно с этим 3 апреля аналогичные события произошли в двух других селениях данного региона – Силпи и Ошихундас, где также пострадали несколько домовладений. Эти селевые потоки носили чрезвычайный характер, поскольку отложения были перемещены на большое расстояние и аккумулировались на большой площади, что говорит о том, что и будущие события будут иметь катастрофические последствия в связи с появлением новых построек. Агентство Ага Хана Хабитат предприняло многочисленные меры по уменьшению рисков, такие как расчистка и организация новых русел, а также внедрение экспериментальной системы раннего оповещения для местного населения.

Ключевые слова: *Каракорум, Гиндукуш, изменения климата, неравномерные осадки, система раннего оповещения, селевой поток, мероприятия по уменьшению угрозы и риска*

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Introduction

Debris flows and flash floods are most destructive mass movement phenomena abundant in alpine environment [*Dowling, Santi 2014*]. The most common cause of these flows is saturation of debris with runoff during sudden and intense precipitation on high steep, poorly vegetated slopes [*Nash et al., 1985; Georgakakos, 1986; Sweeney, 1992; Borga et al., 2007*]. The mountainous region has plentiful supply of non-lithified sediments produced by weathering, slope degradation, and glacial processes, deluge of debris when moves down the slope causes loss of life, destruction to habitat and infrastructure. Climate change will have significant influence on the frequency of the mass movement particularly debris flow and flash floods [*Winter et al., 2010; IPCC 2012; 2013; Gobiet et al., 2013*]. Borga et al., 2014, illustrated the effect of climate change on debris flow with special reference to changes in rainfall intensity and pattern, in combination with increased temperatures, which is to increase the frequency and magnitude of debris flow, provided with ample amount of sediment. A warmer climate tends to increase rains, thus increasing the area contributing effectively to runoff [*Stoffel and Beniston, 2006*]. Likewise, [*Tomczak & Ewertowski, 2017*] have thoroughly studied the geomorphological processes and concluded that, receding glaciers have also influenced glacier associated hazards such as, debris falls, slides and flows, down wasting and back wasting of melting of dead ice.

Debris flows vary in size and nature, they include small creek activation on the scree slopes, catastrophic events produced by flash flooding and sudden outburst of glacial lake. The landscape evolution in high-mountain areas and is often strongly influenced by debris flows [*Zimmerman & Haeberli, 1992*]. Debris flows have major role in shaping landscape of Gilgit Baltistan GB in Northern Pakistan. There have been events which had far reaching predicament such as debris flow of Shishkat in 1974 [*Goudie et al, 1983*] which dammed the river creating 12 km long artificial lake up ahead. Similarly, event of Gupis in 1980 created lake which extended 5 km upstream submerged two villages and rendered 500 people homeless [*Nash et* *al., 1985*]. Moreover, recent GLOF event on 17th July 2018 from Badswat glacier brought huge sediment load blocking Ishkoman River forming an artificial lake, around 30houses submerged under the lake.

Communities in rural areas of GB particularly Ghizer district are by far most affected by debris flows. Ever increasing population, lack of land use planning has led people to settle in hazardous areas. As [*Chang et al., 2009; Tripathi et al., 2014*] put it, the mass wasting vulnerability has been increasing, in some way, result of encroachment into flood and debris flow prone areas worldwide. Sherqilla is one of the most vulnerable villages in district Ghizer which has been experiencing debris flows in past with limited damages. However, during the unusual and devastating rains on 3rd April 2016, a high magnitude debris flow event occurred in Sherqilla from Danjir nala Rahimabad living zone. As a result, 20houses were totally washed away and people were forced to leave in makeshift tents and host families. Considering the flashflood frequency and exposure of population AKAH, WWF and Gilgit Baltistan Disaster Management Authority (GBDMA) selected Sherqilla village for pilot intervention of Community Based Flood Early Warning System (CBFEWS) under Upper Indus Basin (UIB) initiative. Moreover, to reduce the risk of debris flow emergency funds were utilized to mitigate the immediate threat. This study encompasses detail insight into the impact of pilot mitigation project on infrastructure and human life and effectiveness of Early Warning System (EWS) based on risk management Plan.

Study area

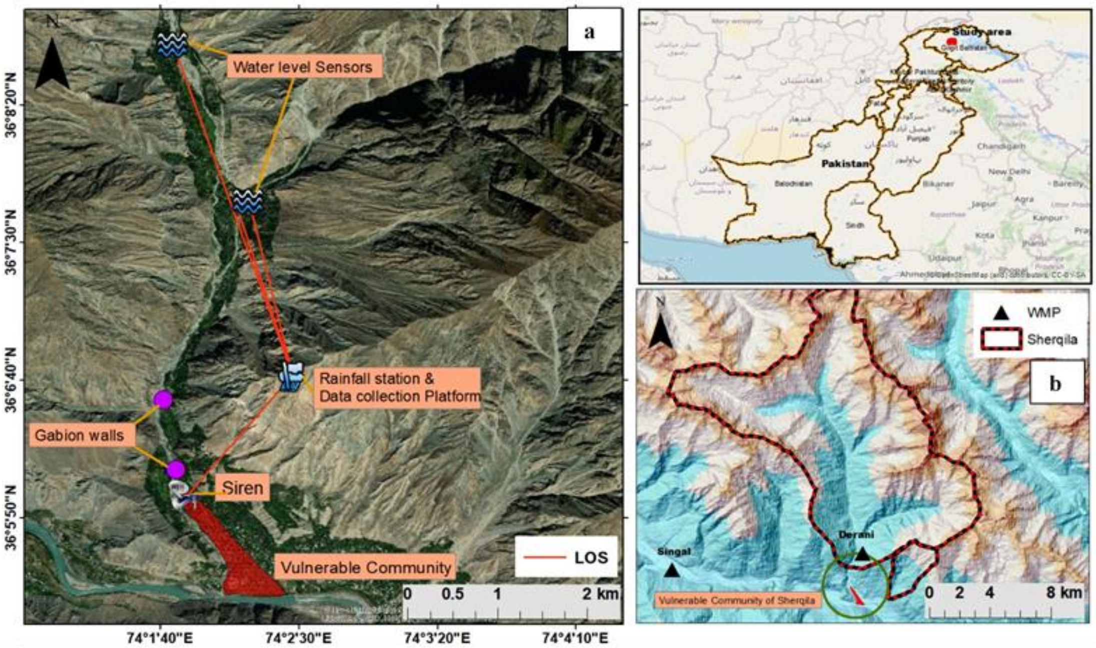

Fig. 1. a) Highlights the location of CBFEWS with its components and mitigation work done by AKAH to reduce flashflood risk. b) Map showing the location of Weather Monitoring Posts (WMPs), Derani and Singal

Sherqilla village is situated along the left bank (northern side) of Ghizer River providing home for 1500 household 12000 individuals at around 40 km west of Gilgit city. Most of the inhabited area (7 km stretched, 1.5 km widespread) is settled on debris fans and partially on the river terraces especially the lower areas along the river. A perennial stream named Derani nala along the NW end of the village is passing partially through settled areas. The stream is further divided into two valleys Derani and Bilchar with a catchment area of 163 km^2 covered with glaciers, rock glaciers and snowcapped peaks. This torrent is vulnerable for flashfloods and has history of floods and damages downstream, where CBFEWS installed for warning. Moreover, AKAH with the help of local government authorities initiated the channelization of a proper track for debris flow at Danjir nala, and mitigation work (gabion walls) built at critical points in Derani perennial stream to reduce the risk of flashflood to settlements. Likewise, the already installed Weather Monitoring Posts (WMPs) at Derani and Singal village played a key role in this study.

Brief review of the problem

Rainfall-induced debris flow and landslides have potential to cause widespread damages, resulting in many fatalities and massive damages to economy around the world [*Salvati et al., 2010; Borga et al., 2014; Melillo et al., 2014*].

The impacts of climate change and its influence on initiation of debris flow is debatable topic for many researchers [*Matthews et al., 2009; Bollschweiler and Stoffel, 2010; Jakob and Friele, 2010; Stoffel, 2010*]. Some research studies documented that the global warming might influence the frequency of extreme rainfall events [*Fowler and Hennessy, 1995; Easterling et al., 2000; Fowler and Kilsby, 2003*] and they concluded that such variations in climate might trigger more debris flow events in future.

There is a close association between the rainfall type and the occurrence of extreme events [*Starkel, 1979*]. The intensity of rainfall and duration, antecedent rainfall, and combination of both determine the rainfall pattern which trigger various debris flow events. Rainstorms of with extreme (high) intensity with short interval time may cause increase surface runoff due to inadequate infiltration and absorption of rainwater [*Wieczorek and Glade, 2005*].

Debris flow in glacier environment are caused by retreat of glacier snout, movement of unconsolidated material over barren land and occasionally ice-cored glacial sediments, which are mobilized by flash floods due to subsequent extreme rainfall, snowmelt, and glacial lake outbursts [*Haeberli, 1992; O'Connor and Costa, 1993; Evans and Clague, 1994; Haeberli et al., 1997*]. Mountain ranges in northern area of Pakistan, hosts some of the world’s largest mountain glaciers causing various hazards and disasters such as glacier dammed lakes [*Jamil, 2019*]. GLOF induced flashflood and debris flow from Badswat glacier in 2018 continued for 12 days resulting in deposition of huge sediment load blocking Ishkoman river forming an artificial lake. Luckily, no causalities reported as the event occurred during the daytime, if it would have happened at night damages would have been enormous.

Various debris flow events in these mountain ranges have caused number of deaths and economical damages, unfortunately there is limited literature on debris flow events triggered by glacier lakes, rain fall and snow melt. One of reason of limited studies in these remote areas is scarcity and unavailability of ground data which can be used for analysis of triggering factors such as rainfall and temperature. Installation of WMPs and EWS readily resolve this data gap in coming future.

Method and data

A combination of field and remote sensing data is employed for this study, rain fall data from Pakistan Meteorological Department (PMD) and WMP data of AKAH. The atmospherically corrected Sentinel-2 optical data (Band: B2-B8, B11 and B12) image data was acquired from Google Earth Engine (GEE) for calculating the snow cover area of study area for year 2016 (25th March-10th September). The S2 images were available as 12 UINT16 spectral bands representing SR scaled by 10000 with four spectral bands (Blue band (0.490 μm), Green band (0.560 μm), Red band (0.665 μm) and Near-infrared (NIR) band (0.842 μm)) at 10 m spatial resolution. A cloud free image collection was used to prepare composite with median *ee.Reducer* function. The median composite image was latter analyzed to derive snow cover of the area using supervised classification method utilized in GEE platform.

Along with sentinel-2 data, Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) was used to derive topographic features of study area such as slope and aspect in ArcGIS platform. The already available data on hazard vulnerability and risk assessment data is retrieved from the HVRA database of

AKAH Pakistan. Post mitigation work assessed through field studies and analysis of information through GIS and its impact deduced.

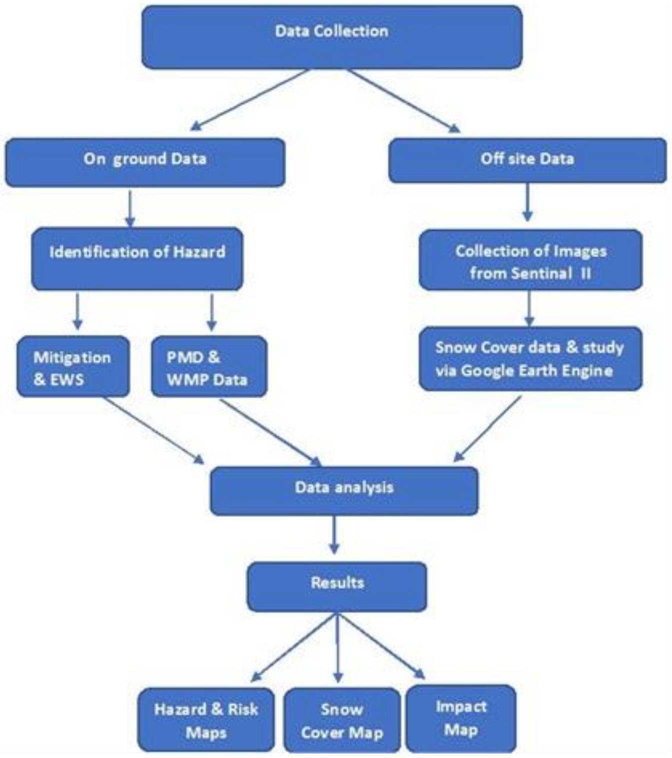

Fig. 2. Methodology flow chart for the study at Sherqilla

Analysis and results

Precipitation analysis

High-intensity precipitation at global scales [*Beniston, 2009; Giorgi et al., 2011*] supports the view that the global hydrological cycle is intensifying because of global warming and the associated increasing water vapor content and energy in the atmosphere. Consequently, in many areas, the flash flood and debris-flow hazard is expected to increase in severity, through the impacts of global change on climate, severe weather in the form of heavy rains and river discharge conditions [*Kleinen and Petschel-Held, 2007; Beniston et al.,2011*]. The frequency and intensity of the disaster events have increased in the last decade due to climate change and changes in the rain fall pattern. Rainfall or runoff can cause a soil mass to fail and can trigger debris flow [*Iverson, 1997*]. [*Rasul et al., 2014*] also studied the effects of rainfall and subsequent rise in temperature in increasing in melt water. The WMP data at Derani suggest that the 50mm intense rain fall coupled with the higher melting of the snow in short time has triggered the debris flow event on 3rd April 2016. Such events are also expected in near future if the erratic rain fall happens.

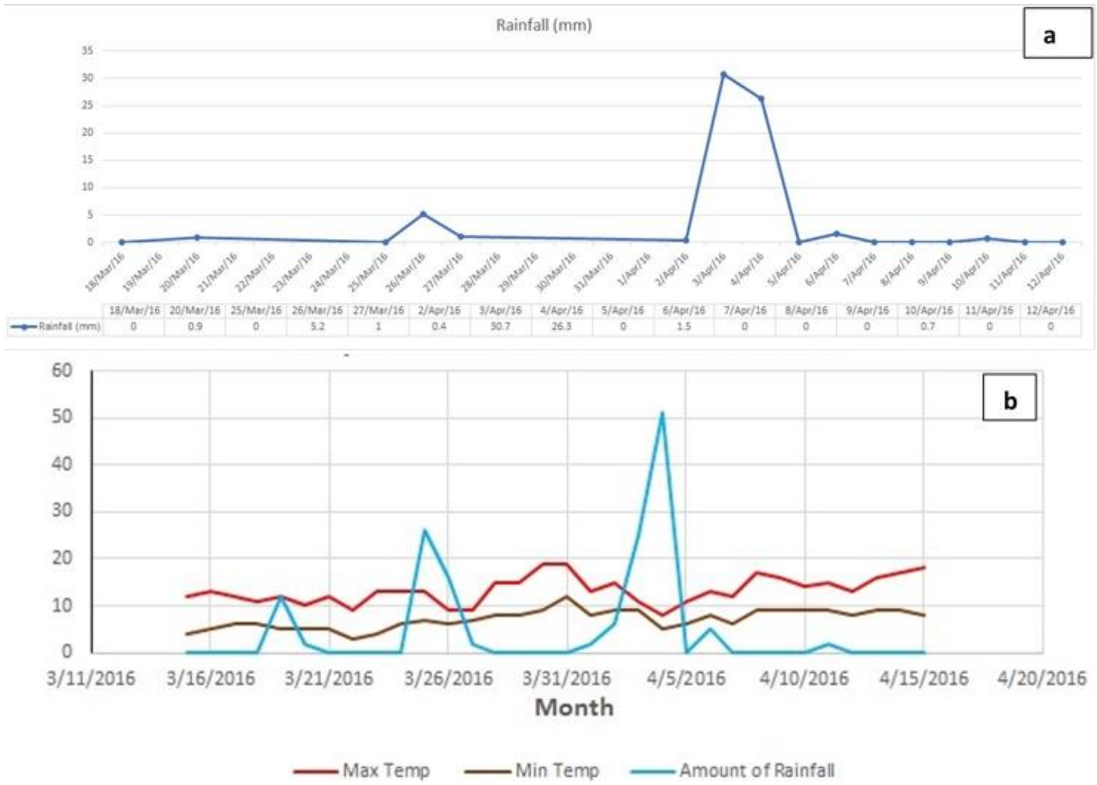

Fig. 3. a) The rain falls trend of Pakistan Meteorological Department (PMD) data of Gilgit station. b) Weather Monitoring post (WMP) data of Derani village by AKAH

Failure process

Rainfall, sometimes combined with snowmelt, is the main factor triggering most debris flows [*Wieczorek and Glade, 2005*]. Accurate rainfall data are crucial for early warning, as well as for defining rainfall thresholds and for predicting debris-flow volume [*Nikolopoulos et al., 2014; Marra et al., 2016*]. Short very intensive rain fall observed and recorded around 30.7mm at Gilgit PMD station, and above 50mm as recorded by WMP Derani, simultaneously debris flow & flashflood triggered on 3rd April 2016 at Oshikhundass (Gilgit), Sherqilla & Silpi in Ghizer district resulting in damages of houses, orchards and infrastructure. Rain fall coupled with the snow melt might have triggered the debris flow in Danjir nala of Sherqilla that damaged twenty houses and hundred became exposed to future events. Moreover, snow avalanches were also recorded at Derani village as highlighted in WMP data at the same time as thresholds were met. Many debris flows were triggered by locally intense convective rainfall characterized by a very small storm cell [a few kilometers or even less across; *Underwood et al., 2016*]. Similar phenomenon of localized rainfall had occurred in July 2006 in Gitch village at 5am early morning, a prayer facility collapsed, and 7 people died, however no rain observed in Sherqilla few km downstream. In the month of august same year limited rainfall observed at the catchment of Damass at around 12pm, in few minutes when viewed from upper Gahkuch a black snake of debris was moving down in Damass village damaging building, orchards, channel, roads etc.

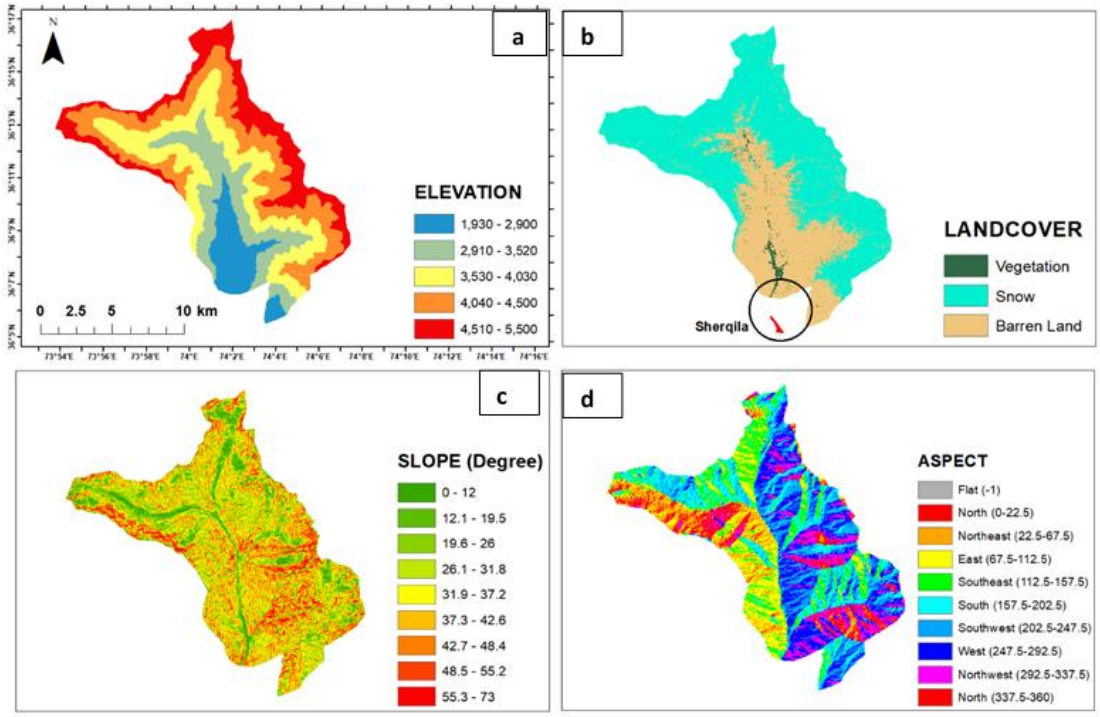

Fig. 4. a) Elevation map of both catchments Danjir & Derani. b) Showing landcover of the sources area. c) Display of variation in slope of the terrain. d) Presenting aspect of both the perennial & dry nala

Mitigation and Early Warning System

The rainfall triggered debris flow event in 2016 further aggravate the risk scenario. People were afraid of next event and reluctant to live in same place, they were planning to relocate to safer area, even they identified a placed for future settlement and AKAH conducted the assessment. Rebuilding or relocating of affected people to a new place is a very complex and sensitive issue as it often results in unintended negative social issues [*Barenstein, 2015*]. Moreover, settlement in a new area without any basic amenities such as water, electricity, and accessibility are very difficult and time taking. Considering the future risk, mitigation measures seemed only option, budget proposed and undertook the mitigation in 2017-18. Regulating the debris flow from catchment area down to the exit in river was a challenging engineering intervention. The catchment area 7.5km² was assessed for the possibility of cost effective and practically viable intervention. Feasibility of the channelization were conducted by the geologists and engineers of AKAH to verify the flow pattern, soil type, rock type and topo. They came up with the channelization of old debris track the ultimate option to regulate the flood to main Ghizer River. Keeping the previous flow pattern of debris and catchment orientation for the future debris, a channel with rectangular section was designed and excavated. A total length of 853.5m, average depth & width of 4m and 7.5m respectively with average gradient 15˚ from apex to bottom of fan. Around 23786 m³ soil was excavated and transported outside via loader tracker. The stone/small pieces of rocks and excavated soil were dumped on both sides of the channel to give it extra capacity, which almost double the depth of the channel.

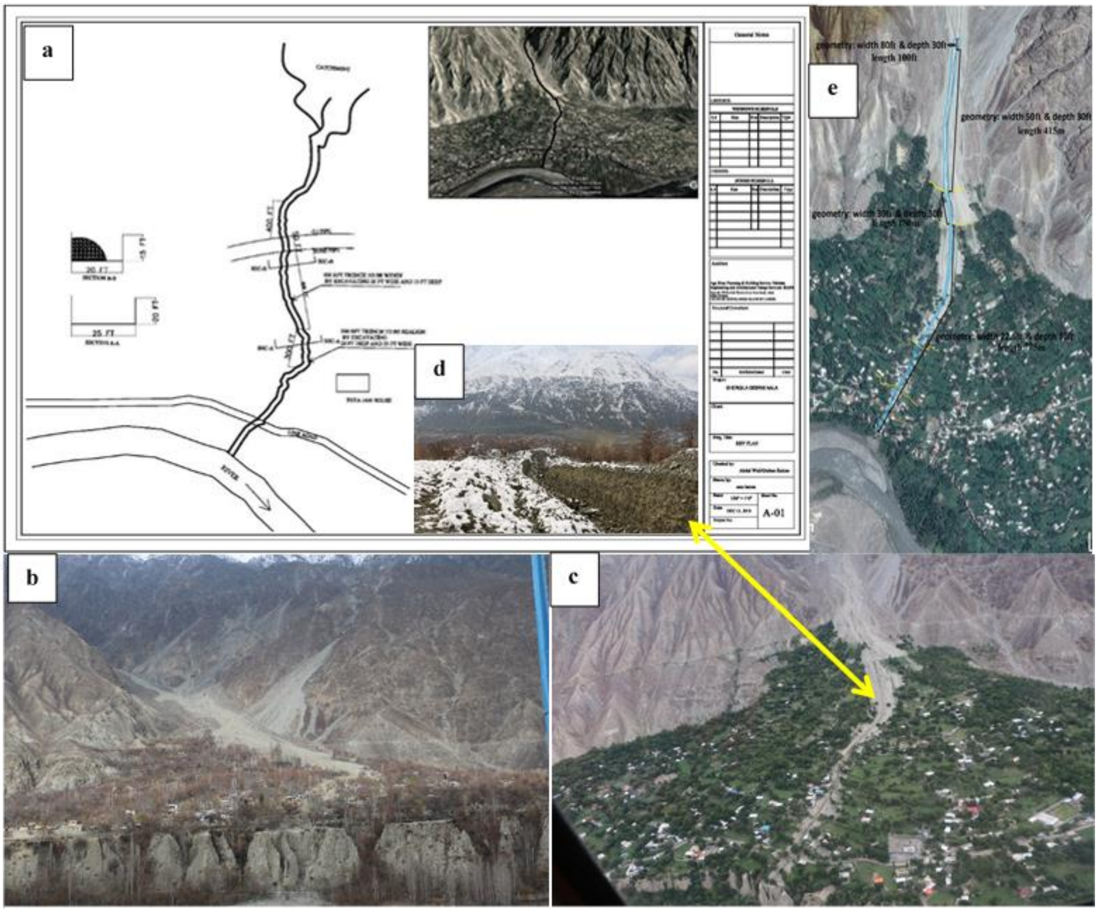

Fig. 5. a) Indicates the typical design of the mitigation for excavation of the channel. b) Norther view of the debris fan with the spread of the debris as viewed across Ghizer River in December 2016. c) Airborne view of the mitigation work as taken from AKDN Heli in July 2018 during aerial survey of Badswat GLOF. d) Southern view of mitigation work after completion in January 2019. e) Proposed design on Google Image

The designed system at Sherqilla included, Wireless Remote Terminal Unit (WRTU), Data Collection Platform (DCP), Audio Remote Terminal Unit (ARTU) and tipping bucket. The water content sensor is installed at a location elevated from the normal discharge of water, flood level increases and when touches it, transmit information through radio waves and GPRS to data collection platform. From here the information is transmitted to ARTU and siren activated to trigger alarm for early warning. After the capacity building on installation by the vendor at Islamabad a pre-feasibility survey for the installation of the early warning was conducted through remote sensing shown in Fig. 6b and the exact locations were identified for the fixing of the systems on the ground, which were installed on the pre-identified sites and the system was tested successfully. The community based early warning system installed at Sherqilla a populated village of district Ghizer from mid-May to mid -June 2017.

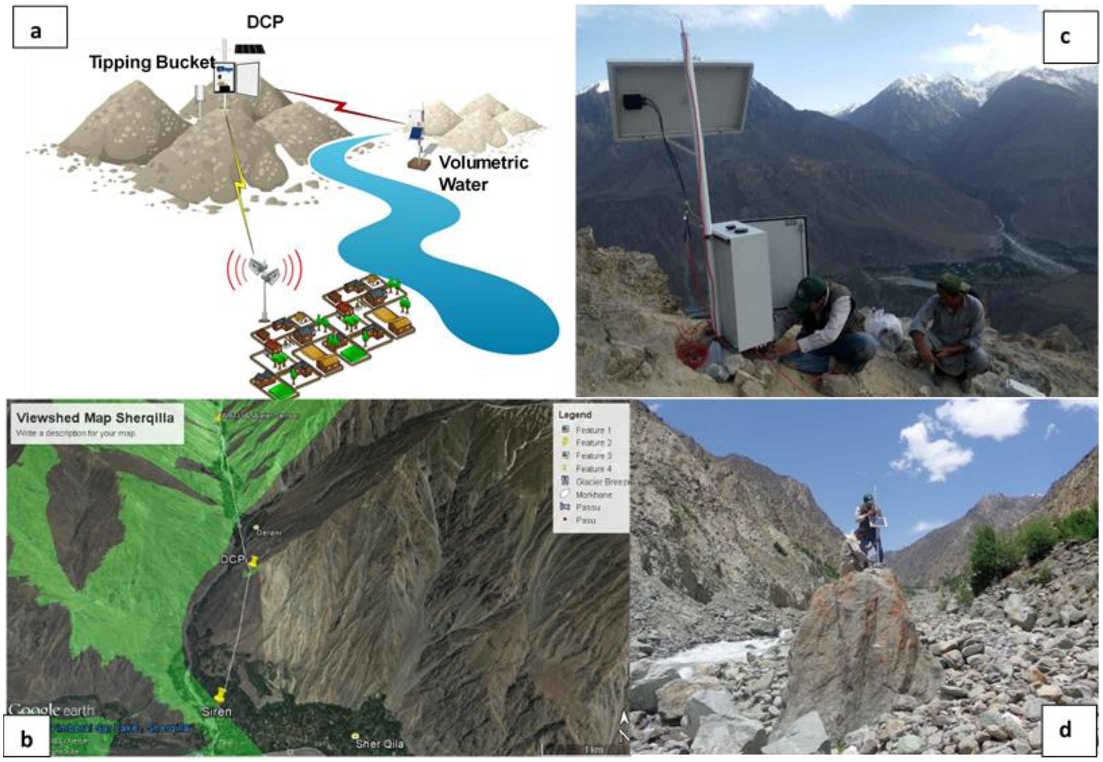

Fig. 6. a) Describes the early warning system and its components i.e. water content sensor, data collection platform, tipping bucket and siren system. b) Selection of site through the remote sensing to view the line of site for EWS. c) AKAH staff installing DCP at the identified site. d) Installation of water content by staff. Photo Credit AKAH Pakistan

Impact of risk management initiatives

During the 2016 debris flow event the flood marked its path across the fan and reached the Ghizer River damaging houses & infrastructure in the way. In case of future events the debris could divert in 180˚ direction from the apex of fan damaging all in the way down. Around 300houses are dwelling on the fan were highly exposed, the excavation of channel and permitting a proper path for debris has reduced the risk of overtopping into settlements saving the precious lives, livelihood, agricultural lands of area 211,007 m^2 and other infrastructure as reflected on the post hazard map of Sherqilla. In addition, another intervention of gabion wall on the hotspots reduce the diversion of flood to village and agricultural land area 54,253m^2 saved on NW side of village along the Derani perennial stream. Hazard dynamics were changed both size of high and medium hazard zones reduce whereas low hazard zone slightly increased as displayed in Fig. 7-8.

In all types of preparedness and response strategies, early warning systems play a key role. As such, early warning systems, specifically developed to generate and disseminate timely and meaningful warning evidence for event risk management, represent an essential part of an effective natural hazards preparedness tool [*UNISDR*, *2009; European Commission*, *2007*]. On the same lines AKAH installed CBFEWS, ultimately enhanced the preparedness and capacity of vulnerable community. Ali, 2020 has expressed the success of pilot EWS, the National Disaster Management Authority (NDMA) recognized the success of CBFEWS for Sherqilla, where an early warning transmitted by the system during the flood event at around 4 AM on 3 August 2017 as shown by in Fig. 9b, helped communities in Sherqilla evacuate to safer area with time lapse of 1hr. Fida Ali (CERT Captain), from Sherqilla, expressed the community’s satisfaction of EWS: “Before installation of the system, we would spend entire nights at the upstream of Derani village, so that we could provide warning to downstream vulnerable community in Sherqilla. Now we can all sleep-in peace”.

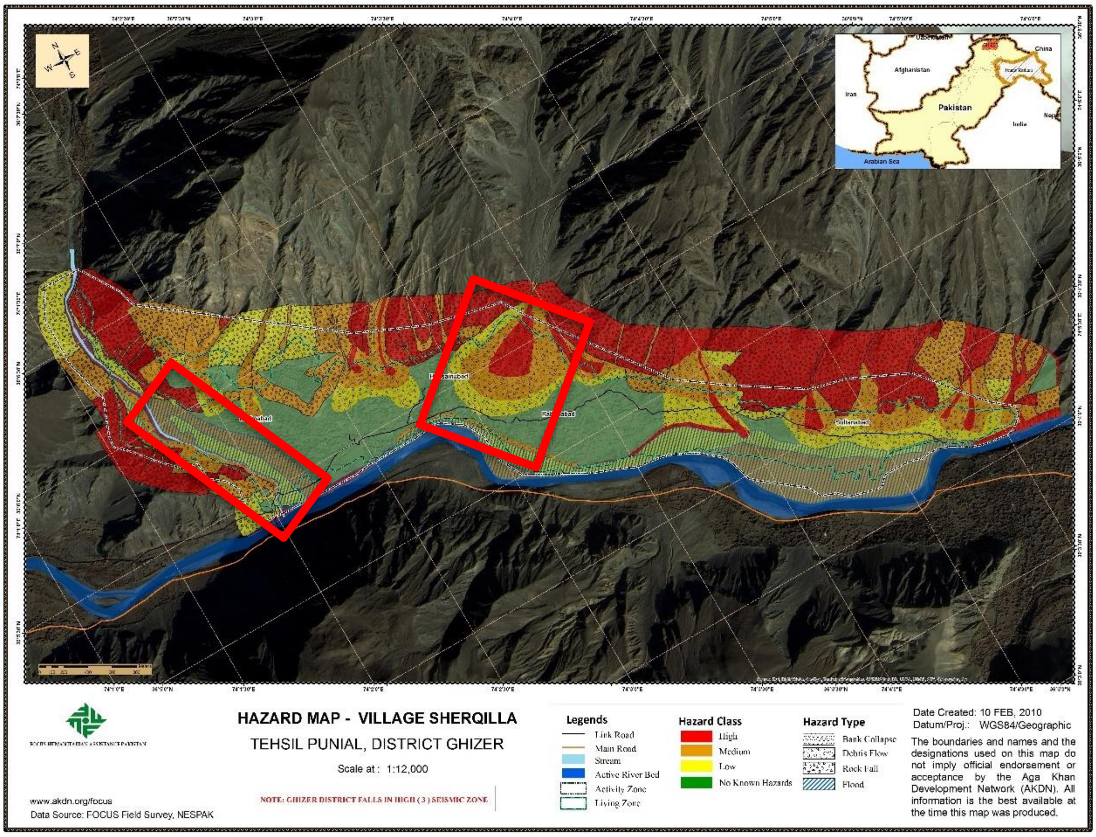

Fig. 7. Hazard map of Sherqilla before the mitigation work in the central portion (debris flow hazard dominant) and NW side of village (flashflood dominant)

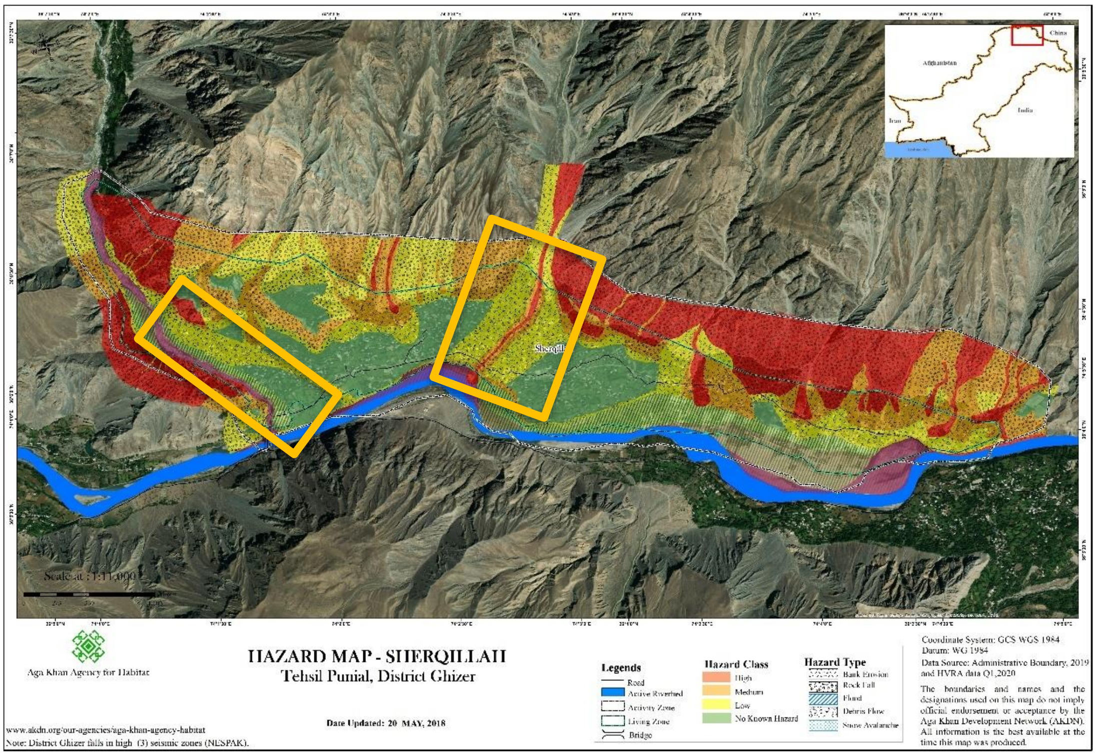

Fig. 8. Hazard map of Sherqilla indicating the reduced risk (medium to low) after the excavation of channel for debris in the central portion and NW side of village after construction of gabion structures

Table. Comparison of changes in the hazard dynamic after the imitation at Danjir nala

Before the mitigation		**After the mitigation**	
Hazard	**Area, km^2**	**Hazard**	**Area, km^2**
High	0.000065	**High**	0.00026
Low	0.000241	**Low**	0.000191
Medium	0.001437	**Medium**	0.00045
Total	0.001743	Total	0.000901

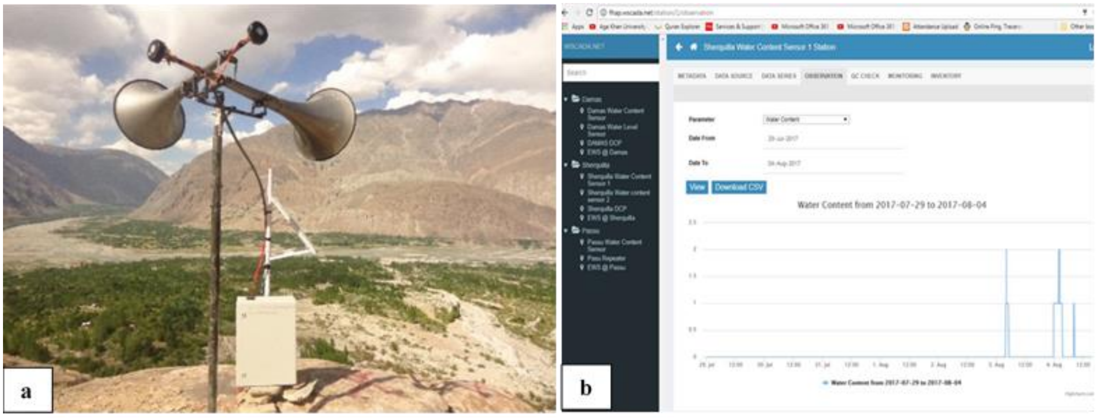

Fig. 9. a) A view of the siren system with ARTU. b) A screen shot of online portal indicating the trigger of siren on 3rd August 2017. Photo Credit: AKAH

AKAH interventions

Sherqilla village is one of the vulnerable villages of district Ghizer exposed to multi-hazards, debris flow and flashfloods being the dominant hazards. Soon after the flood AKAH Pakistan provided food and non-food items to the affected people and gave makeshift shelters to live. It was a challenge to regulate the stream of the intensive debris flow. Prior to this intervention the flow of debris has been freely spreading across the debris fan, damaging forest, agricultural land, houses, and other infrastructures. In 2017-18 mitigation work was initiated with the help of local government authorities, AKAH Pakistan spent around 9million PKR on excavation of channel to give a proper route to debris flow. While the government paid the compensation of the land to make it a successful pilot intervention.

AKAH Pakistan, WWF and GBDMA signed a tripartite agreement in June 2016 for co-implementation of *"Installation of 2 Early Warning Systems"* in flood prone areas of district Ghizer. In the same year after connection during monsoon a flashflood event occurred from Derani nala of Sherqilla during the night at around 4am as shown on Fig. 9b. It however did not damage any house but caused minor damages to irrigations channels, link roads, orchards, and trees. People timely evacuated to safer areas after the trigger of the early warning. The timely dissemination of early warning and evacuation of the people is a success story and vouch the success at Sherqilla.

Conclusion

The unusual debris flow event occurred at Sherqilla in the month of April triggered by erratic rain, which was one of its kind in the region. Such events cannot be ignored in future with changing climate. This combined effort by AKAH, government and local community reflect the risk management initiatives in terms of pilot mitigation and installation of early warning system. These initiatives provided the platform for upscale the early warning mechanism and experimental mitigation in the Gilgit-Baltistan which can be replicated in regional countries.

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