Glacier hazard associated with surging glaciers – story of the Shishper Glacier from Hunza, Pakistan

D. Karim[1], I. Karim[1], W. Anwar[1], K. Uddin[1], A. Ali[1], D.R. Gurung[2]

[1]Branch of the Aga Khan Agency for Habitat in Pakistan, Gilgit, Pakistan, deedar.karim@akdn.org

[2]Branch of the Aga Khan Agency for Habitat in the Republic of Tajikistan, Dushanbe, Tajikistan

Abstract. Glaciers in Karakoram like Khurdopin, Shishper and Gulkin are exhibiting surging phenomenon as a resulted of which hazard like Glacial Lake Outburst Flood (GLOF), flood and debris flow are real. The Shishper glacier which started surging from January 2018 till August 2019 covered around 2500m in total and achieved maximum average surge rate of 36m per day between 21st May to 25th June 2018. The surging glacier damaged newly constructed irrigation channel for hydro-electric generation unit due to which power shortfall was observed in central & lower Region of Hunza. In addition, intake- irrigation channel and drinking water supply for central Hunza was also damaged which created drought like situation, drying up thousands of orchards impacting livelihood of local community. The surging Shishper glacier blocked Muchowar valley in mid-November 2019 and resulted in formation of glacial lake which breached through a gradual release in June 2019 and January 2020 causing medium level flooding. The flood event of 23rd June 2019 resulted in estimated discharge of 3500cusecs which is thrice the peak discharge in summer. The flood event was much smaller than expected which may be due to low temperature during the months. With the ice mass from the surge still intact the problem is far from over. The cycle of lake formation and release of water could likely repeat again in future and regular monitoring of situation is important.

Key words: *surging glacier, GLOF, Karakorum, Shishper, glacier dammed lake*

Cite this article: Karim D., Karim I., Anwar W., Uddin K., Ali A., Gurung D.R. Glacier hazard associated with surging glaciers – story of the Shishper Glacier from Hunza, 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. 234–245.

Гляциальные опасности, связанные с пульсирующими ледниками, – история ледника Шишпер (долина р. Хунза, Пакистан)

Д. Карим[1], И. Карим[1], В. Анвар[1], К. Уддин[1], А. Али[1], Д.Р. Гурунг[2]

[1]Филиал Агентства Ага Хана по Хабитат в Пакистане, Гилгит, Пакистан, deedar.karim@akdn.org

[2]Филиал Агентства Ага Хана по Хабитат в Республике Таджикистан, Душанбе, Таджикистан

Аннотация. Ледники в Каракоруме, такие как Хурдопин, Шишпер и Гулкин, имеют пульсирующий характер. В результате, здесь существует реальная угроза прорывных паводков, наводнений и селевых потоков. В результате очередной пульсации ледника Шишпер, длившейся с января 2018 г. по август 2019 г., площадь ледника увеличилась на 2500 м. Средняя максимальная скорость подвижки достигала 36 м в сутки и наблюдалась с 21 мая по 25 июня 2018 г. Пульсация ледника повредила недавно сооруженный ирригационный канал ГЭС, из-за чего в центральной и нижней частях долины р. Хунзы наблюдались перебои с подачей электроэнергии. Кроме того, был поврежден водозаборный ирригационный канал и прервана подача питьевой воды в центральную часть долины р. Хунза, что создало близкую по своим последствиям к засухе обстановку: пострадали тысячи фруктовых садов, что отрицательно сказалось на жизнеобеспечении местного населения. Пульсация ледника Шишпер в середине ноября 2019 г. привела к перекрытию долины р. Мучовар и образованию ледниково-подпрудного озера, которое прорывалось в июне 2019 и январе 2020 гг., вызвав тем самым наводнение среднего уровня опасности. Паводок 23 июня 2019 г. имел расход около 3500 м^3/с, что в три раза превышало пиковый летний расход реки. Паводок оказался намного меньше, чем ожидалось, что может быть связано с низкой температурой в течение месяцев. С учетом того, что ледяная масса все еще остается в долине, проблема далека от решения. Цикл формирования озера и сброса воды из него, вероятно, может повториться в будущем, и регулярный мониторинг ситуации имеет большое значение.

Ключевые слвоа: *пульсирующий ледник, прорыв ледникового озера, Каракорум, Шишпер, ледниково-подпрудное озеро*

Ссылка для цитирования: Карим Д., Карим И., Анвар В., Уддин К., Али А., Гурунг Д.Р. Гляциальные опасности, связанные с пульсирующими ледниками, – история ледника Шишпер (долина р. Хунза, 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. 234–245.

Introduction

Global climate change is evident from receding glaciers that will have effects on downstream communities. Changes in cryosphere and corresponding impacts on physical conditions across high-mountain system is the most directly visible phenomena induced by global warming. This is also one of the primary reasons why glacier observations have been used for monitoring climate system for many years [*Haberli 1990; Dyhrenfurth, 1955*] was probably first to coin the term The Third Pole for the Hindukush, Karakorum Himalayan (HKH) region since it has the highest concentration of snow and glaciers outside the polar regions. Although global climate change is inducing glaciers retreat in general, some of the Karakorum glaciers are indeed surging. Hewitt, 2005 reported that most glaciers of the Karakoram Himalaya which receded from 1920s to early 1990s began surging in the late 1990s. [*Copland et al., 2011*] also came across various surge type glaciers during his study in Karakoram region. The Karakoram glaciers have received substantial scientific attention because of the anomalous regional mass balance [*Kääb et al., 2015*] and the large number of surging glaciers [*Paul, 2015*].

Typically, there are two phases in surging glacier having a certain year cycle. Active phase of glacier surge is characterized by large amounts of ice rapidly (by a factor of ten or more compared to normal flow velocities) gets transported from higher accumulation zone to a lower frontal area. It is followed by quiescent phase when ice flow slows or becomes stagnant allowing ice to melt over years to decades in the new ablation area while new snow and ice accumulate in the reservoir area, building up mass for a possible next surge [*Jiskoot, 2011*]. Downstream implications associated with surging glaciers are thoroughly discussed by [*Kreutzmann, 1994; Iturrizaga, 1996, 1997*]. Although these glaciers serve as important water resource for irrigation purposes, but dynamism of glacier terminus and associated floods possess threat to downstream villages. Most common phenomena associated with surging glacier activity is glacier-dammed lake and subsequent sudden release of lake water in a form of GLOFs. Glacier-dammed lakes are comparatively short-lived and often exists only for several months or years catastrophically draining ultimately. The lakes generally empty during summertime when meltwater discharge high [*Iturrizaga, 2005*].

Surges of Shishper Glacier have been documented since 1892–93 and the recent surges occurred in 1974 [*Conway, 1894; Mason, 1930; Goudie, 1984; Hewitt, 2014*]. During the surge events the lower tongue pushed further into the valley and blocked the proglacial flow of

Muchowar Glacier on several occasions resulting in an ice-dammed lake. Similar situation was observed and well documented in case of Khurdopin Glacier [*Quincey and Luckman, 2014*] and Kyagar Glacier [*Round et al., 2017*]. Sudden release of Shishper Lake had caused destruction of infrastructure in the downstream and threat still looms large. This article presents timeline of most recent surge event, monitoring of lake and subsequent outburst that resulted in destruction.

Study area

Hasanabad is resourceful village located adjacent to Aliabad town of Hunza district and at ~95km from Gilgit city. The studied Shishper glacier is located 5km NE of Hasanabad. The perennial Hasanabad stream originates from Muchowar and Shishper valley. Shishper glacier is one of the surging type glaciers mostly fed by the snow avalanches through the rugged mountain topography. Six tributary glaciers are contributing to this glacier, the main trunk has a length of around ~14.5 km with a catchments area of 110 km^2 and total of 344 km^2 including Muchowar valley. Hasanabad stream has a history of floods and GLOF events from surging of glacier of both glaciers in the valley. The study area is important from the point of electricity generation for Hunza Valley (Hasanabad power complex: 1200 KW (Phase-I, 200KW (Phase-II, and 500KW (Phase-III). The elevation ranges within the watershed from 2000 to 7,700m.a.s.l. While the mean annual precipitation is 125 mm and average temperature is 11 °C [*Shah et al., 2019*].

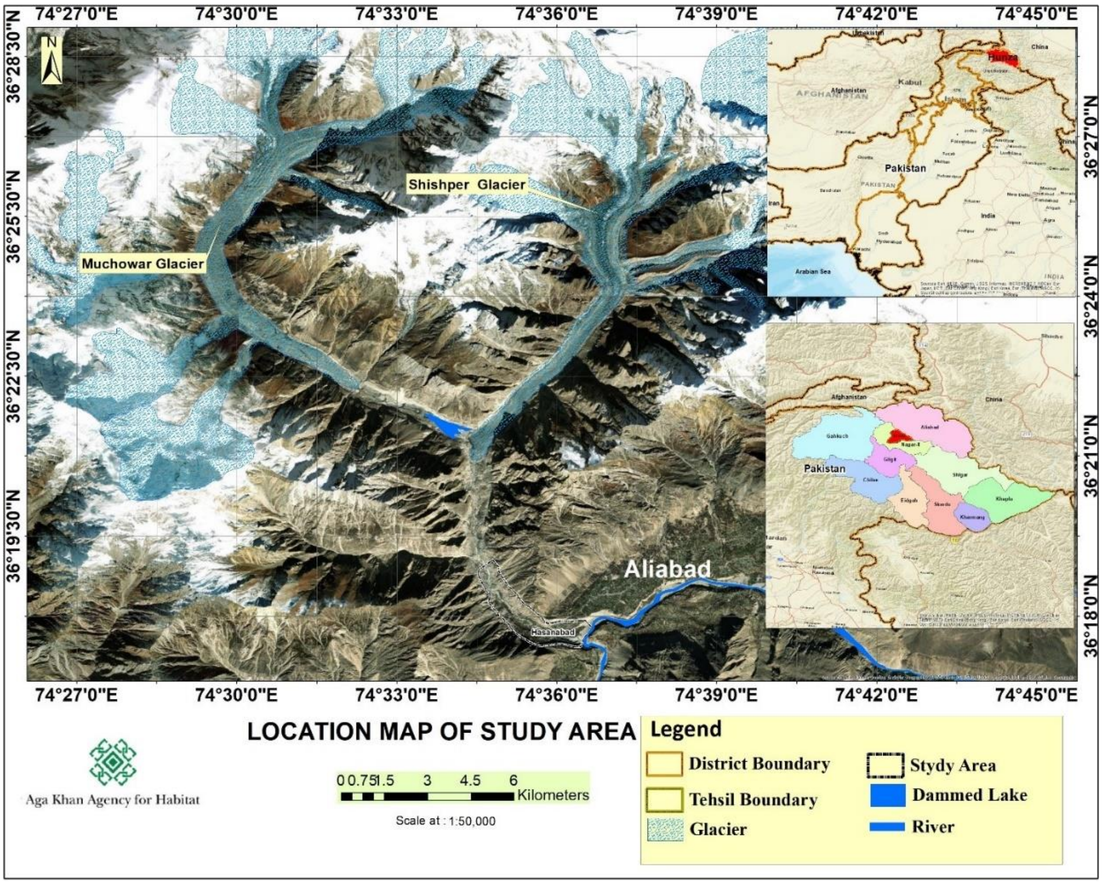

Fig. 1. Location map of study area of Shishper Glacier

Brief review of the problem

Shishper glacier has a long history of surging since the 1892–93 and the recent surges occurred in 1974 [*Conway, 1894; Mason, 1930; Goudie, 1984; Hewitt, 2014*]. However, in last surge both Muchowar and Shishper came in contact and space was not available to form lake, but still flood occurred, and one person lost his life. The advance and retreat cycle for Shishper glacier is ~45 years (personal communication with local community) 20 years for Khurdopin [*Hewitt and Liu, 2010; Quincey & Luckman, 2014*], and 8 years for Gulkin (personal communication with local community). Probably there is a link between glaciers length, catchments area and weather that effect the flow cycle. [*Falátková, 2016*] assessed 38 cases of GLOF event due to breach of moraine dam across the Himalaya and reported ice avalanche falling into the lake (34%), hydrostatic pressure as a result of the lake level rise (20%), and melting of dead ice (14%) as three most common causes of GLOF in Asia. In case of Shishper, hydro-static pressure played a key role in release of the lake through the sub-glacial conduit, as active surge had impeded sub-glacially flow of water.

In the Karakoram and Hindukush Mountains, a seasonal pattern dominates the outburst chronologies. The failures of ice-dammed lakes mostly occurred between July and August during the time of the highest discharge and temperature. Most of the dams fail periodically with irregular possible return intervals of about 1-2 years. The lakes often drain in successive years due to internal changes in the ice barrier itself [*Iturrizaga, 2005*]. The Shishper lake emptied gradually through scrupulous release between 17th and 23rd June with high flood level of ~3500cuses as recorded at KKH bridge by AKAH on mid night of 22nd June 2019. It again formed in 1st week of October which drained in 3rd week of January 2020 when temperature was cold, a unique outburst case in winters. The Shishper lake drained with a discharge of 142 m^3/s between 22–23 June 2019 as reported by the Pakistan Meteorological Department. [*Hussain, 2018*] stated that there is chance of drainage of the glacier dammed lake slowly through crevasses in summer season. The glacier dammed area has slope between 5-25˚ while upstream area where lake has formed has slope greater than 25˚. This shows that the pressure of lake water on glacier blockage may have increased by day as water level/volume increased. The lake started to form again in October 2019 when temperature was below freezing, though the reservoir volume decreased due to the reduced height (10m) of the glacier (AKAH revised report 25th Dec 2019). According to [*Rasul et al., 2011*] huge amount of water was stored under snout of many glaciers during super floods of 2010 especially in case of Booni and Passu glaciers which caused mysterious outbursts in the past. A GLOF in month of January 2008 from Passu glacier was recorded with warm and muddy water, it was unique case of GLOF in winters and surprise for general and scientific community. Similar phenomenon occurred between 14th-18th January 2020 from Shishper and proglacial lake drained with maximum discharge ~1000 m^3/sec and without damages.

Surging glaciers pose great threat to downstream communities, infrastructure, habitat, lives & livelihoods. If the glacier advances across river valleys it forms an ice-dammed lake with potential of devastating outburst floods [*Ashraf et al., 2012; Quincey et al., 2014; Round et al., 2017; Steiner et al., 2018; Bhambri et al., 2019*]. During the glacier surge it had damaged the under-construction channel and intake chamber of new hydropower, both channels and two intakes of water channel for Aliabad, and suspension bridge and pipeline ride over. In flood event of June 2019 intakes of hydropower station, channels, link road, KKH, agricultural land on both sides of stream eroded. [*Hewitt et al., 2019*] suggest that, monitoring of glacier surges, ice-dammed lake formation and drainage is essential. AKAH followed the same and monitored glacier both on ground, through drones and aerially in critical time.

Method and data

The Shishper glacier and formation of lake was brought to our notice by the local community. Immediately AKAH fielded experts from and visited Shishper glacier on 23rd November 2018 to assess the situation. The team interacted and interviewed local community members about the history of the surge, past GLOFs and damages. A detail report was prepared highlighting the possible future scenarios. Furthermore, benchmarks were signposted through color with numbers in field, and GPS coordinates were taken to measure the rate of surge of the glacier.

The GIS experts have developed temporal map of study area using Sentinel-2 and Landsat images. Online historical images were downloaded from land viewer (https://eos.com/landviewer). Using ArcGIS software, the experts developed temporal maps for measuring movement of glacier and changes in size of the lake over the time.

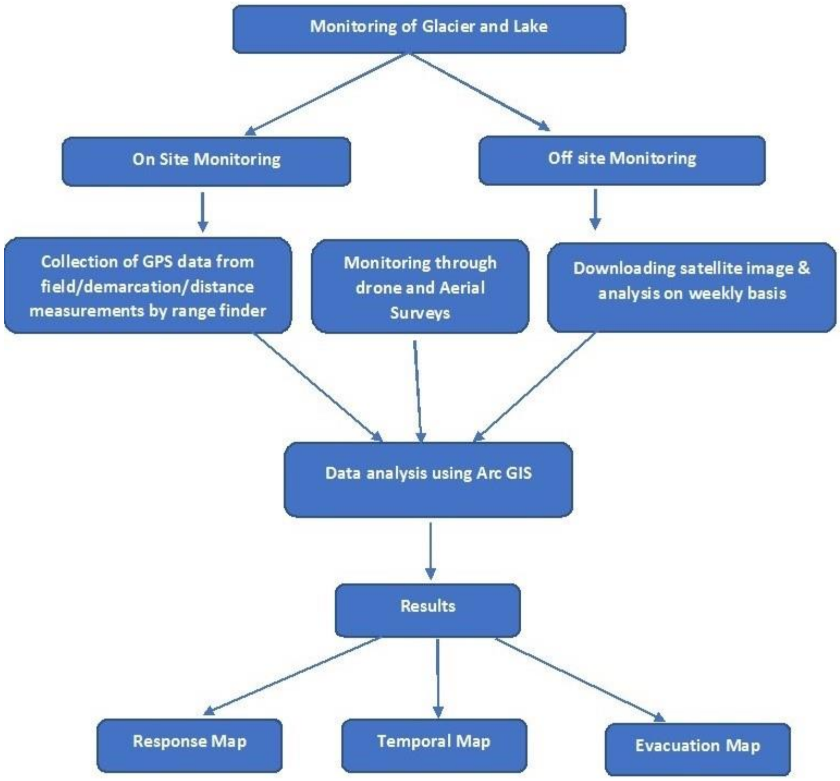

Fig. 2. Flow chart showing methodology adopted for the research work

Ground monitoring

During the initial assessment in mid-November benchmarks were established on visible features like boulders, walls of irrigation channel, bridge, and intake chambers with the distance measurements. By recognizing the relative positions of these “natural benchmark” a vector computation is possible allowing measuring local glacier displacements, limited only by the number of recognizable features. The glacier displacement was measured according to the new approach, already tested on Liligo Glacier in Karakoram, Pakistan [*Diolaiuti et al., 2003*]. The dimensions were measured through the range finder from the same targets and rate of glacier surge calculated. Measurement of glacier front usually are based on repeat surveys (often along predefined bearings) from a reference point placed at a certain distance from the glacier, in order to measure fluctuations in time [*Bonardi et al., 2006*]. Moreover, repeat photography by digital camera were deployed to visualize the changes and fluctuations in the trunk of glacier, and height of snout was analyzed using basic trigonometry considering angle from reference point to the top of the glacier snout measured with inclinometer. The discharge measurements were done using flow meter. The monitoring was made on weekly, biweekly, and monthly basis. However, visiting the glacier regularly by experts was not possible from Gilgit, therefore Community emergency response teams (CERTs) were trained on the monitoring of the glacier and equipment were provided for twice a week monitoring.

Fig. 3. a) Frontal view of snout and marked boulders for monitoring rate of glacier surge. b) CERT team taking measurements from the benchmarks during the training. c) AKAH geologist measuring velocity of water near snout by velocity meter while CERT team observing. Photo credit AKAH Pakistan

Monitoring through UAVs, remote sensing and aerial surveys

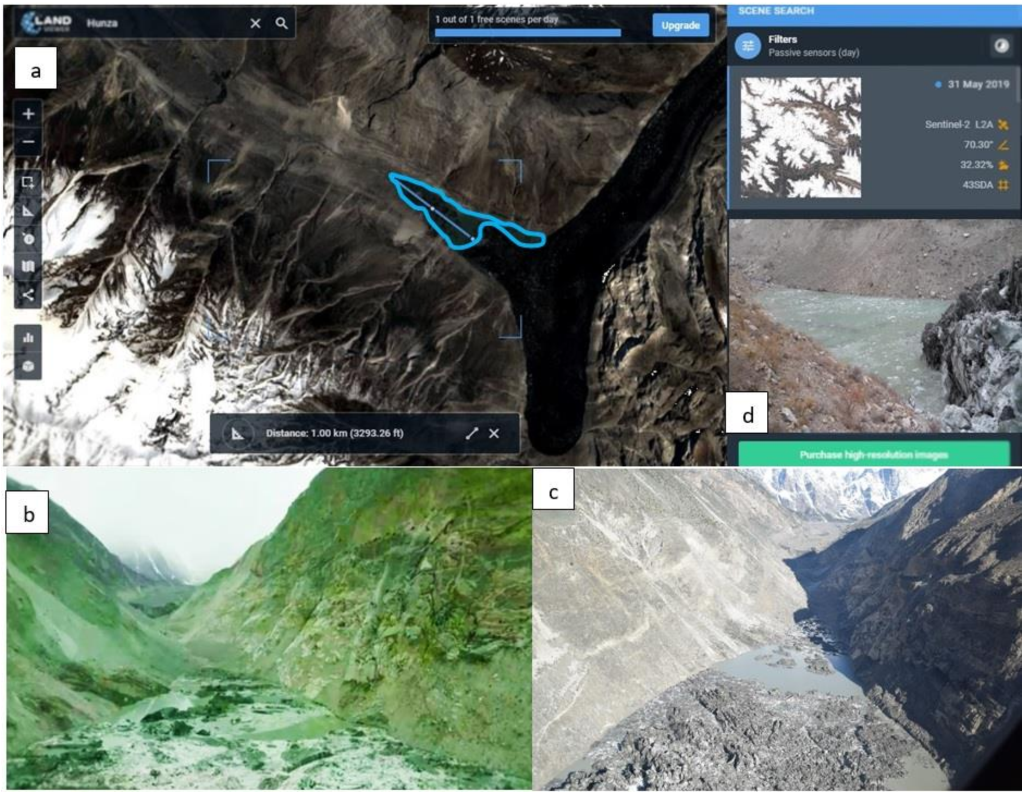

Fig. 4. a) Sentinel-2 L2A Image as of 31st May 2019 showing lake. b) Drone Image of Shishper glacier dammed lake taken on 20th May 2019. c) Aerial borne picture of lake taken on 25th May 2019. d) Image of developing lake on 25th November 2018 taken by Sher Khan tours & tracking expert from Aliabad Hunza

With the passage of time the glacier was growing laterally and vertically both upstream towards the Muchowar valley pushing the lake water and downstream to Hasanabad village. [*Chang-chun et al., 2011*] mentions that as an important way of obtaining spatial data, UAV remote sensing has the following advantages: real-time measurement, flexibility in usage, high-resolution, low costs, and easy to collect data in unfavorable environmental conditions. With advancing of the glacier downstream the accessibility of the lake was not possible, so the only option to assess the lake was through UAVs and remote analysis of the satellite images.

Drone such as DJI Phantom4 from Gilgit Baltistan Disaster Management Authority (GBDMA) and DJI Mavic by Frontier Works Organization (FWO) were utilized for the remote assessment and monitoring of the glacier and dammed lake on weekly and bi-weekly basis. Land viewer based weekly images were another source of remote monitoring analysis of the notorious glacier and lake.

Analysis and results

Surge process and chronology, rate of lake growth

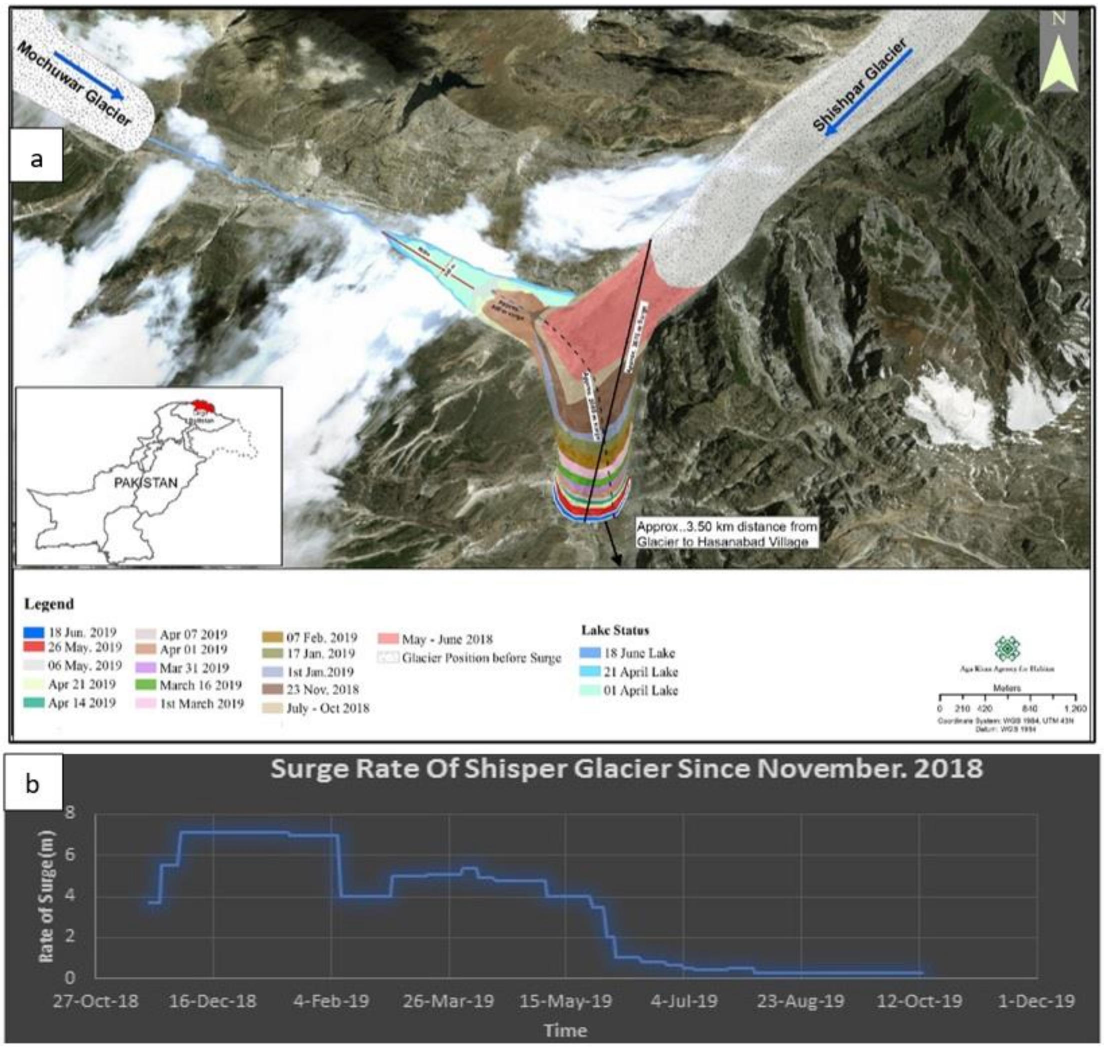

Fig. 5. a) Temporal map of Shishper glacier by AKAH show the surging of glacier and lake development over the time. b) Graph indicates rate of surge of Shishper glacier over the time. Data by AKAH

Ground surveys and maps advocated that the two tributaries Shishper and Muchowar glaciers retreated and had separated into distinct glaciers by 1954 [*Paffen et al., 1956; Hewitt et al., 2019*]. As a result of surge of Muchowar both glaciers met again before 1972, however local community witnessed that both glaciers connected in 1974 with no lake formation.

Shishper glacier was surging at a rate of 36m/day between 21st May- 25th June 2018 with a surged ~1100m in 30th days. The glacier hit the opposite rocky mountain perpendicular to the direction of moving glacier on 17th November 2018, blocked the Muchowar valley forming a glacier dammed lake. After blockage in last week of November average rate of surge was 3.7m/day. The movement gradually increased with average rate peaking at 7m/day in Jan-Feb 2019, which declined sharply to 4m/day in March probably due to increased size of the basin. From mid-March again increase in movement noticed till 7th April, further the average rate steadily declined and reached ~1m/day as shown in Fig. 5b before the GLOF eventually happened. From May 2018-June 2019 the glacier has covered around 2.5-3 km, on the other hand it has pushed the lake ~600m towards the Muchowar glacier.

Failure process

Commonly glaciers experience a variety of trigger mechanism, such as surge waves due to avalanches and rock fall into the lake, moreover, calving of glacier, landslides and slope failures. Failure of subglacial and ice-dammed lake drainage through the progressive enlargement of subglacial channels due to frictional shear and erosion is also common [*Nye 1976; Clarke, 1982*]. Shishper glacier unlike Khurdopin glacier which drained when temperature increased in March, continued to surge with average rate of 5m/day, chocking, blocking and release water in the form of minor floods. On the other side, water fluctuation in the stream was also experienced and minor flood on 11th June with 1100 cusecs of discharge. Partly cloudy weather condition from 20th May to 14th June 2019 created cooling effect and delayed the release of water. Finally sub glacial flow between 17th-23rd June 2019 occurred with peak flood recorded on mid night of 22nd June reflected on graph in Fig. 7. Reductions in temperature and increase in moisture and cloudiness, when coupled with the reductions in insolation in the ablation zone of the glacier can have a cooling effect, with decreased river runoff being the natural consequence [*Fowler and Archer., 2004, 2006; Tahir et al., 2011; Forsythe et al., 2017; Bashir et al., 2017*].

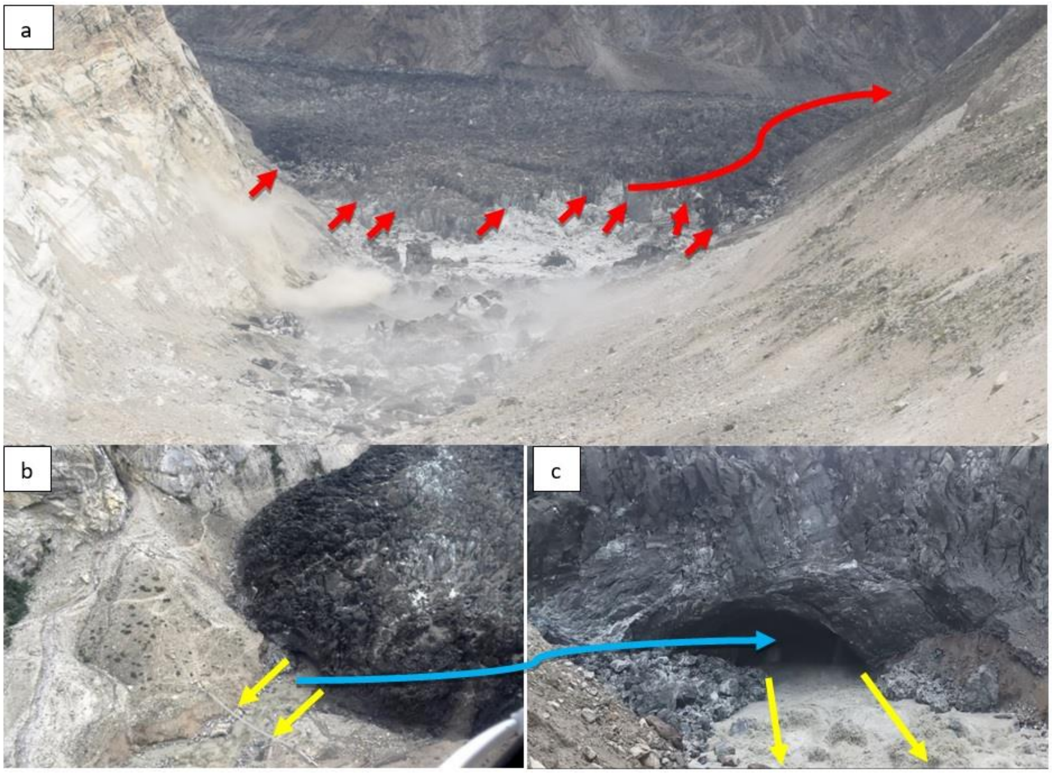

Fig. 6. a) Aerial picture taken on 23rd June 2019 downstream view of released dammed Lake from Muchowar glacier after release of water from the lake on with crevasses and openings. b) Airborne view of glacier outlet. c) Front view of outlet taken from the suspension bridge. Photo Credit AKAH Pakistan

Impact of surging glacier on downstream

During the rapid surge Shishper glacier engulfed ~850m channel section and intake chamber of newly constructed power station and intake. It also damaged segment of Aliabad-Hyderabad irrigation channel which was the only water supply source for ~5 Km² agricultural area of upper portion of Aliabad, Dourkhun and Hyderabad. Many trees in upper reaches which was over 30years old dried due to damage of channel and drought like situation. Moreover, 300meter pipeline of drinking water supply and suspension bridge were damaged. Blockage of water by the glacier also severely affected the hydro-power generation during the winters.

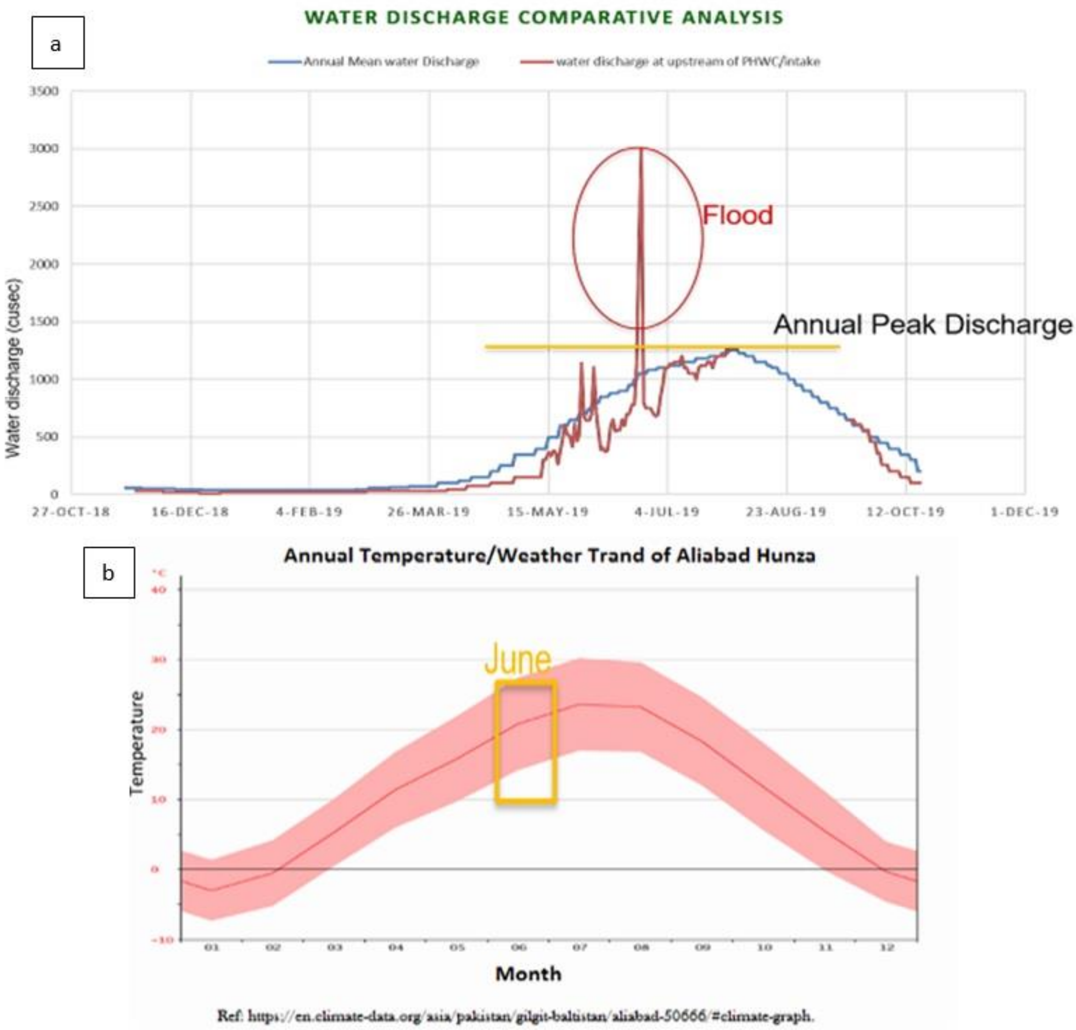

Fig. 7. a) Blue line in graph indicates the monthly mean discharge while the red line shows the normal and flood peak discharge data by AKAH Pakistan. b) Temperature trend for Central town of Hunza Aliabad by as recorded by Pakistan Meteorological Department (PMD)

Water release started from 17th June 2019 onwards and gradually increased continuously till 21st June, the flood peak discharge recorded at mid night of 22nd June which chronicled above 3000 cusecs at RCC bridge on KKH as shown in Fig. 7a. The flood discharge was estimated thrice of annual average peak water discharge of the stream, and eroded both banks of Hasanabad stream, damaged four irrigation channels, drinking water supplies, water channel of Hasanabad powerhouse, newly constructed retaining wall just upstream of the RCC bridge were completely damaged and 50 cattle's swept away. Agricultural land eroded on both side of the nullah due to this erosion and collapse caused blockage of KKH at two locations.

AKAH's interventions

Since the formation of lake in mid-November 2018, AKAH Pakistan closely monitored Shishper glacier through on-site field assessment, monitoring through benchmarks, repeat photography and remote sensing using free source latest satellite images of Landsat-8 and Sentinel-2L.

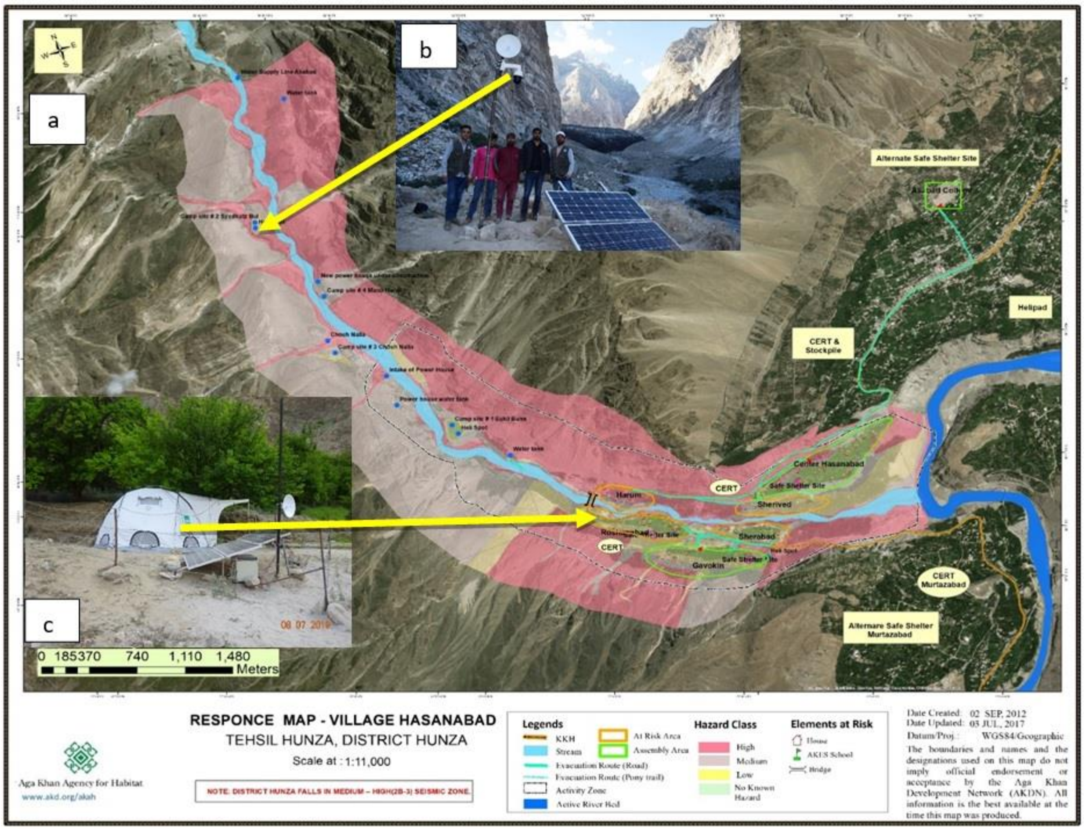

Fig. 8. a) Response map for Hasanabad considering GLOF, green areas identified as safer area, orange polygons are the vulnerable settlements, blue line demarcates the evacuation routes. b) The picture above in center shows the CCTC camera. c) Indicates the monitoring camp. Photo Credit AKAH Pakistan

The report with future scenarios was shared with Gilgit-Baltistan Disaster Management Authority (GBDMA), local government and AKDN agencies for further action and monitoring of the surging glacier. AKAH & GBDMA jointly conducted downstream vulnerability assessment, identified safer areas, safe evacuation routes for worst case scenario. The worst-case scenario relates to lake remains intact till May-June 2019 and more catastrophic outburst happens with possibility of overflow of lake coupled with piping resulting higher discharge and damaging flood. Awareness sessions, mock drill completed with the help of local government to prepare community to cope with disaster and follow safe evacuation routes to safer areas if flood happens.

The glacier dammed lake which was monitored through satellite images on weekly basis was not possible due to partly cloudy- cloudy weather conditions between 20th May to 14th June 2019. Aerial survey was conducted on 14th June followed by second aerial mission on 23rd June to see overall situation across the lake and glacier after release of water by sub-glacial flow. It was observed that lake has almost drained out and the Muchowar stream continuously flowing out sub-glacially from Shishper glacier.

With the increasing flood, CERT members were mobilized to monitor water discharge during the peak flood time to ensure quick response in case of any emergency or critical situation. Stockpile which includes all emergency equipment shifted on both sides of Hasanabad to response timely. The threat is not yet over as retreat of the Shishper glacier to it previous position will take years. Considering the future threat and high probability for reformation of lake, regular monitoring and early warning system are inevitable. Consequently, AKAH installed CCTV based early warning system to give alert to the downstream community in case of flood to save the precious lives and livelihood.

Conclusion

Shishper glacier is a surge type glacier and has history of advancing and retreating cycle. The most recent surge and resultant outburst flooding event reminds us all about the threat that looms large in the highly glacierized terrain. Episodic outflow and timely action by AKAH, GBDMA and local government helped averted major disaster. The involvement of community volunteers in monitoring the situation proves the importance of taking on board communities in disaster risk reduction initiatives. Since the Muchowar glacier remains blocked the possibility of another episode of flood cannot be ruled out. While the threat is not yet over, regular monitoring of the situation is of paramount importance to formulate timely action.

Acknowledgments

The authors would like to thank Nawab Ali Khan (CEO), Salman Shan (EM Head) and Dr. Nazir Ahmed (RPM) of Aga Khan Agency for Habitat (AKAH), Pakistan for their continuous support in overall process from reconnaissance to the final draft. We are especially thankful to GBDMA and FWO for providing the drone images and contribution of Community Emergency Team (CERT) volunteers for monitoring glacier in critical times. We also would like to thank Planet Labs and EOS Land viewer for providing access to their high-resolution imagery.

References

Ashraf A., Naz R. & Roohi R. (2012) Glacial lake outburst flood hazards in Hindukush, Karakoram and Himalayan Ranges of Pakistan: implications and risk analysis, Geomatics, Natural Hazards and Risk, 3:2, 113- 132,

Bhambri, R. et al. Ice-dams, outburst floods, and movement heterogeneity of glaciers, Karakoram. Glob. Planet. Change 180, 100–116 (2019).

Bonardi, L., Catasta, G., Righetti, F., D'Adda, S., 2006. Manuale di Osservazioni Glaciologiche. I Quaderni del Servizio Glaciologico Lombardo, 5. Servizio Glaciologico Lombardo, Milano, 47 pp.

Chang-chun, L.; Guang-Sheng, Z.; Tian-jie, L.; A-du, G., 2011, Quick image-processing method of UAV without control points data in earthquake disaster area: Trans. Nonferrous Met. Soc. China Vol. 21, pp. 523-528.

Clarke, G.K.C., 1982. Glacier outburst flood from &Hazard lake', Yukon Territory, and the problems of #ood magnitude prediction. Journal of Glaciology 28, 3}21.

Copland, L.; Sylvestre, T.; Bishop, M.P.; Shroder, J.F.; Seong, Y.B.; Owen, L.A.; Bush, A.; Kamp, U. Expanded and recently increased glacier surging in the Karakoram. Arct. Antarct. Alp. Res. 2011, 43, 503–516.

Conway, W. M. Climbing and Exploration in the Karakoram Himalayas. (T. Fisher Unwin, 1894).

Dyhrenfurth, G. O. (1955). The third Pole – The history of the High Himalaya (1st UK Edition). London: Ex Libris, Werner Laurie.

Diolaiuti, G., Pecci, M., Smiraglia, C., 2003. Liligo Glacier (Karakoram): reconstruction of the. recent history of a surge-type glacier. Annals of Glaciology, 36: 168 – 172

Falátková, K. 2016. Temporal analysis of GLOFs in high-mountain regions of Asia and assessment of their causes. AUC GEOGRAPHICA 51 (2): 145–154.

Godone D. and Godone F. (2012). The Support of Geomatics in Glacier Monitoring:

Goudie, A. S., Jones, D. K. C. & Brunsden, D. Recent fluctuations in some glaciers of the Western Karakoram mountains, Hunza, Pakistan. In The international Karakoram project (ed. Miller, K. J.) 2, 411–455 (1984).

Forsythe, N., Fowler, H. J., Li, X.-F., Blenkinsop, S., & Pritchard, D. (2017). Karakoram temperature and glacial melt driven by regional atmospheric circulation variability. Nature Climate Change, 7. https://doi.org/10.1038/nclimate3361

Fowler, H. J., & Archer, D. R. (2006). Conflicting signals of climatic change in the upper Indus Basin. Journal of Climate, 19(17), 4276–4293. https://doi.org/10.1175/JCLI3860.1

Haeberli, W., 1990. Glacier and permafrost signals of 20th century warming. Annals of Glaciology, 14, p 99-101.

Hewitt. K, 2005. The Karakoram Anomaly? Glacier Expansion and the 'Elevation Effect,' Karakoram Himalaya. Mountain Research and Development Vol 25 No 4 Nov 2005: 332–340.

Hewitt, K. and Liu, J.: Ice-Dammed Lakes and Outburst Floods, Karakoram Himalaya: Historical Perspectives on Emerging Threats, Phys. Geogr., 31, 528–551, https://doi.org/10.2747/0272-3646.31.6.528.

Hewitt. K, et.al., 2019. The hazardous 2017–2019 surge and river damming by Shishper Glacier, Karakoram. Nature Research, (2020) 10:4685

Hewitt, K. Glaciers of the Karakoram Himalaya, Glacial Environments, Processes, Hazards and Resources. https://doi.org/10.1007/978-94-007-6311-1 (Springer Dordrecht, 2014).30. Meier, M. F. Surging Glaciers—The Dilemma Continues

Hussain, A. 2018. A brief communication of Shishper glacier surge in 2018, Hunza river basin, Pakistan. International Journal of Advanced Geosciences, 7 (2) (2019) 124-128

Iturrizaga, L. (1996): Über das Naturgefahrenpotential für die Hochgebirgssiedlung Shimshal (3080 m), Nord-West- Karakorum. – Die Erde 127 (3): 205–220.

Iturrizaga, L. (1997): The Valley of Shimshal – A Geographical Portrait of a Remote High Mountain Settlement and its Pastures with reference to environmental habitat conditions in the North West Karakorum. – GeoJ. Tibet and High Asia IV, 42 (2/3): 305–328.

Iturrizaga, L. (2005): Historical glacier-dammed lakes and outburst floods in the Karambar valley (Hindukush- Karakoram). GeoJournal (2005) 63: 1-47

Jiskoot, H. Glacier surging. In Encyclopedia of Snow, Ice and Glaciers (eds. Singh, V.P., Singh, P., Haritashya, U., Kääb, A., Treichler, D., Nuth, C., and Berthier, E.: Brief Communication: Contending estimates of 2003–2008 glacier mass balance over the Pamir-Karakoram-Himalaya, The Cryosphere, 9, 557–564, https://doi.org/10.5194/tc-9-557-2015, 2015.

Kreutzmann, H. (1994): Habitat conditions and settlement processes in the Hindukush-Karakoram. Petermanns Geograph. Mitt. 138 (6): 337–356.

Mason, K. The glaciers of the Karakoram and neighbourhood. Rec. Geol. Survey. India 63, 214–278 (1930). Nye, J. F., 1976. Water flow in glaciers: jökulhlaups, tunnels and veins. Journal of Glaciology, 17, 181–207.

Paul, F., Strozzi,. T., Schellenberger, T., and Kääb, A.: The 2015 Surge of Hispar Glacier in the Karakoram, Remote

Sens., 9, 888, https://doi.org/10.3390/rs9090888, 2017.

Paffen, K. H., Pillewizer, W. & Schneider, H. J. FORSCHUNGEN IM HUNZA-KARAKORUM: Vorläufiger Bericht über diewissenschaftlichen Arbeiten der Deutsch-Österreichischen Himalaya-Karakorum-Expedition 1954. Erdkunde 1–33 (1956).

Quincey, D. J. and Luckman, A.: Brief Communication: On the magnitude and frequency of Khurdopin glacier surge events, The Cryosphere, 8, 571–574, https://doi.org/10.5194/tc-8-571-2014, 2014.

Quincey, D. J. & Luckman, A. Brief communication: On the magnitude and frequency of Khurdopin glacier surge events. Cryosphere 8, 571–574 (2014).

Round, V., Leinss, S., Huss, M., Haemmig, C., and Hajnsek, I.:Surge dynamics and lake outbursts of Kyagar Glacier, Karakoram, The Cryosphere, 11, 723–739, https://doi.org/10.5194/tc-11-723-2017, 2017.

Rasul, G., Q. Z. Chaudhry, A. Mahmood, K. W. Hyder, Qin Dahe. 2011. Glaciers and Glacial Lakes under Changing Climate in Pakistan. Pakistan journal of Meteorology Vol8, Issue 15

Round, V., Leinss, S., Huss, M., Haemmig, C. & Hajnsek, I. Surge dynamics and lake outbursts of Kyagar Glacier, Karakoram. Cryosphere 11, 723–739 (2017).

Shah.A, Ali.K, et al. (2019). Risk assessment of Shishper Glacier, Hasanabad Hunza, North Pakistan, Journal of Himalayan Earth Sciences Volume 52, No. 1, pp. 1-11.

Steiner, J. F., Kraaijenbrink, P. D. A., Jiduc, S. G. & Immerzeel, W. W. Brief communication: The Khurdopin glacier surge revisited - Extreme flow velocities and formation of a dammed lake in 2017. Cryosphere 12, 95–101 (2018).

Tahir, A. A., Chevallier, P., Arnaud, Y., & Ahmad, B. (2011). Snow cover dynamics and hydrological regime of the Hunza River basin, Karakoram range, northern Pakistan. Hydrology and Earth System Sciences, 15(7), 2275–2290. https://doi.org/10.5194/hess-15-2275-2011

The Contribution of Terrestrial Laser Scanner, Laser Scanner Technology, Dr. J. Apolinar Munoz Rodriguez (Ed.), ISBN: 978- 953-51-0280-9, InTech