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Risk assessment of Shishper Glacier, Hassanabad Hunza, North Pakistan

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Abstract

Over the last five decades the Karakoram Glaciers has revealed irregular behavior and lack of stability. These anomalies lead surge of glaciers and the formation of glacier lakes, and now risk increasing in the context of climate change. The hazard associated with glacier lake outburst floods (GLOFs) has become an increasingly serious threat to the life, property, livelihoods and infrastructure in the Karakoram Mountains of Pakistan. Shishper Glacier Lake in the Shishper watershed areas of central Hunza in North Pakistan, after its latest activity has turned to a highly prone GLOF hazard. Shishper Glacier and Glacier Lake in the North Pakistan can be harmful to the downstream population and have large socioeconomic impacts if an outburst occurs. This study investigated the spatio-temporal changes in Shishper glacier and its glacial lake, and associated risk of potential GLOF hazard. Shishper glacier was assessed on the basis of field survey carried out in December 2018 combine with GIS and remote sensing data for morphometric, land cover change, physical vulnerability and temporal analysis of Shishper glacier. The Glacier has shown an anomalous behavior in the month of July 2018, no prominent lake was observed while in the month of November 2018 a lake with an area of 0.026 km2 was noticed. Similarly, in the month January, 2019 a prominent lake appeared with an area of 0.057 km2. The physical vulnerability results showed that 80% of the area of Hassanabad village is highly exposed to GLOFs hazard, whereas low lying areas along the Hunza River are also susceptible to inundation. The results show that there is immediate danger of catastrophic outburst through downward movement of the glacier. The study recommends the glacier has an anomalous behavior, it is necessary to monitor the glacier and Glacier Lake continuously, and minimize the adverse effects of potential GLOFs risk. We also recommend strong understanding the phenomenon of glaciers therefore, glacier lakes are very important in north Pakistan with respect to GLOF disaster management.

Keywords: Glacier lake outburst, risk assessment, Shishper glacier, Hazard potential.

1. Introduction

The world's highest mountain areas are facing many environmental challenges such as rapid population growth, environmental degradation, Climate Change (CC), and glacial melting, resulting Glacial Lake Outburst Flood (GLOFs) (Cui et al., 2010). The GLOFs event happens when ice is unable to hold the restraining end moraine wall of loss material from the glacier, often underlain by debris, and as a result the sudden releases of water from impounded lake outburst floods. It can cause loss of life, injury, serious damage to property and livelihoods to the downstream communities (Khanal, Hun and Mool, 2005; Gurrung et al., 2017).

According to the Fifth Assessment Report of IPCC (2013), the Earth temperature has raised by 0.85°C in the last three decades. This has major implication on rapid melting of glaciers and formation of new glacier lakes in mountainous regions of the world (Yao et al., 2012; Ashraf, Naz and Iqbal, 2015). The Hindu Kush-Karakoram-Himalaya (HKH) region and its biggest glaciation focus in low and middle latitude regions in the world has also been affected by the Climate Change associated with rising temperatures (Dongtao et al., 2004). GLOFs have appeared as a serious threat in the mountainous region of HKH in last two decades due to increase in population growth, climate change, economic development and many other anthropogenic activities in these areas which were inhabited and were not advanced previously (Khanal et al., 2015; Nie et al., 2017). Global warming has intensified the risk of GLOFs, and in future, such events can increase. GLOFs risk can be reduced through a comprehensive risk assessment and appropriate mitigation measures. To this end, comprehensive evaluation of GLOFs hazard, vulnerability and risk is imperative. However, efforts have been made to establish procedures, approaches and guideline for such an assessment (Carey, Huggel, Bury, Portocarrero, & Haeberli, 2012; Schneider, Huggel, Cochachin, Guille´n, & Garcı´a, 2014; Worni, Huggel, & Stoffel, 2013). Alford (2007), mentioned that socioeconomic vulnerability assessment is a crucial part of a comprehensive risk assessment for disaster risk reduction in mountainous areas together with the hazard and exposure assessment. But procedure and methods are scanty for vulnerability and risk evaluation of potential GLOF events in downstream areas.

Rapid melting and expansion of glaciers is a serious threat in Karakoram and Himalayan region. The Shishper/Hassanabad glacier, south-facing exposed glacier located south of the Batura glacier has stretched significantly toward the south-west direction from northeast. Over the last few years a slight movement was observed in Shishper glacier whereas, in the month of July 2018 a rapid growth was observed. Resultantly, flow of Hassanabad stream has blocked and a glacier lake formed, 1km south-west of Aliabad city, district Hunza, north Pakistan. The glacier lake is highly vulnerable to lives and properties of Hassanabad village and low lying areas along Hunza River. Whereas high cost infrastructures are highly exposed to running hydro-powerhouse, under construction powerhouse and a bridge of the Karakoram Highway (Pamir times, August 2018; Baig, Dad and Salim 2018). The aim of this paper was to assess potential risk of Shishper Glacier and Glacier Lake and suggest some mitigation measures. The specific objectives of the paper is i) morphometric analysis of the Shishper watershed, ii) Assessing land cover change and glacier movement between 2015-2018 and iii) physical vulnerability assessment.

2. Study area

Hassanabad is a small village adjacent to Aliabad city, Hunza, Northern Pakistan. Karakorum Highway crawls through the study area. Hassanabad ravine (naalah) originates from Shishper and Mochowar glaciers, and runs toward the south, joining with the adjacent Hunza River. The total watershed area is approximately 359 km2 (Fig.1). The study site (36° 15′ – 36° 30′N latitude, 74° 28′ – 74° 39′ E longitude) comprises the Hassanabad watershed in district Hunza, north Pakistan. The Shishper Basin is extremely prone to Glacier lake outburst flood because of the swift advancement of Shishper Glacier and blockage of Hassanabad naalah. An integrated approach was adapted to assess the potential risk of Shishper GLOF by integrating Geo-morphometric assessment, land cover change and temporal analysis, physical vulnerability assessment and community perceptions on Shishper glacier. The study area has an essential role in hydro-power generation for Hunza Valley (Hassanabad power complex: 1200 KW Norwegian unit, 700 KW Chinese unit and 2000 KW Diesel generated power station). The elevation ranges within the watershed from 2000 to 7,700 m.a.s.l. While the mean annual precipitation is 125mm and average temperature is 11 °C.

3. Material and methods

An integrated approach was adapted to assess the potential risk of Shishper GLOF by integrating Geo-morphometric assessment, land cover change and temporal analysis, in addition to physical vulnerability assessment and community perceptions on Shishper glacier. The data required are obtained from the following sources. Advance Spaceborne Thermal Emission and Reflection (ASTER) Digital Elevation Model (DEM, 30m ground resolution) was downloaded from the National Aeronautic and Space Administration (NASA), open Geo-database. Basin modeling technique was applied in a GIS environment to demarcate Shishper Basin and extracted drainage network by using ASTER DEM as input spatial data. Eight Geo-morphometric factors were added by applying established Hortonian and Strahler Geo-morphological laws. Remote sensing techniques can be used to assess the land cover classes and land cover change. Satellite images have served a great deal in the land use, land cover classification of different landscape components on a larger scale (Ozesmi and

Bauer, 2002). Satellite data for 3 years consisted of multi spectral data acquired by Sentinel-2 satellite in the month of September provide by Sentinel-ESA. ERDAS imagine 2014 was used, preprocessed for geo-referencing, mosaicking, and sub-setting of Area of Interest (AOA) from the image. Shishper watershed was classified into four main classes (snow and clean glacier, debris glacier, vegetation and barren land) on the bases of specific Digital Number (DN) of various landscape elements. The maximum likelihood algorithm was utilized for supervised classification of the image.

An evaluation of physical vulnerability indicates the documentation of the exposed essentials at risk and is usually described as the negative impact of hazardous events on susceptible elements. (Karagiogos et al., 2016). In this study, multiple approach was used to determine physical vulnerability such field observations, local community participation in the identification and mapping of susceptible elements combines with GIS and remote sensing techniques.

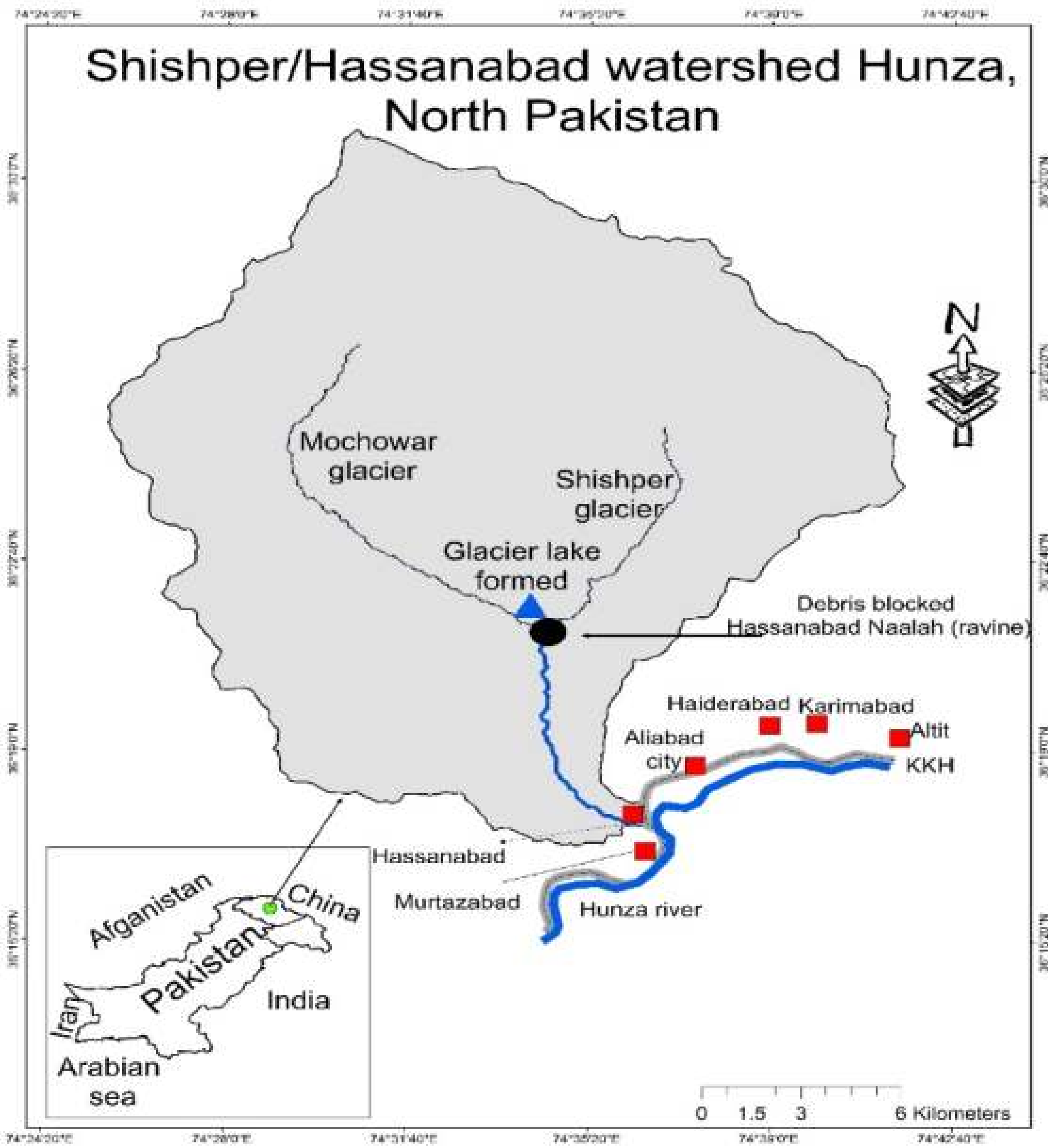

Fig. 1. Location map of study area.

4. Result and discussion

4.1. Morphometric analysis

The results of morphometric analysis of the Shishper Basin are presented in Table 1 and 2 and in Figure 2. The total area of the watershed is 359 km2 while the perimeter is 88km. The watershed's elevation ranges from 2000 m.a.s.l in the south to about 7700 m.a.s.l in the north. Overall, 61% of the area fall between 4000m to 7,700m altitude, whereas glaciers normally accumulate more snow in the winter. Overall, north, northeast and east aspect cover 29% of the basin area, 46% of the area covered by south, southeast and southwest aspect whereas 25% area covered by west, northwest and north aspect. The watershed covered 28% of the area by very steep slope class (48°-78°), while 45% of the area covered by steep slope (28°- 47°) whereas 20% of the area covered by low and moderate slope (12°- 27°). According to Horton (1945) drainage density is the total stream length per unit area of a basin. Poorly drained basin has drainage density 2.74, while well drained has 0.73. The drainage density of the Shishper watershed is 0.33 km/km2. Steam frequency shows the texture of the drainage network, which depends on lithological conditions of a basin. However, stream frequency characterized by steeper surface, impermeable subsurface material, high surface runoff, sparse vegetation and high relief setting. The stream frequency of Shishper watershed is 0.14 per km2.

The circularity ratio of a basin indicates the rate of infiltration and reach time for the excess water in the outlet of the basin, which depends upon lithology, geological conditions and vegetation cover. The circularity ratio of the Shishper watershed is 0.58, indicating a less elongated basin, which also revealed a strong structural control on drainage development. The watershed indicates a uniform rate of infiltration as well as it can take long time to reach excess water to the basin outlet. Elongation ratio indicates the shape of a drainage basin, and the ratio usually runs from 0.6 to 1.0 in a broader range of climatic and geological setting. The elongation ratio for the watershed is 0.8 which indicate oval shape basin with high relief and substantial slope. Drainage texture indicates channel spacing in a fluvial dissected terrain which depends on a number of natural factors such as lithology, soil type, climate and vegetation. Smith (1950) classified drainage texture as follows: <2 very coarse, 2 - 4 coarse, 4 - 6 moderate, 6 - 8 fine, >8 very fine. The drainage texture of the Shishper watershed is 4.05 which indicate coarse drainage texture. It seems that the massive and resistant rocks and high relief have produced very coarse to coarse drainage texture basin. According to Strahler (1964) total number of streams and stream types in a watershed is called stream ordering. Shishper watershed is designated as a fourth-order basin.

4.2. Land cover change and observation of glacier movement

The distribution and change in land cover during the three years is given in Table 3. The land cover category of snow and clean glacier increased from 97 km2 to 123km2 from 2015 to 2018. Similarly, debris glacier also increased from 64 km2 to 84 km2 from 2015 to 2018. An increase was observed in snow and clean glacier from 27% to 34% and debris glacier from 18% to 21% during these three year period. Whereas the slight decline was observed in the case of vegetation, a total of 44 km2 (13%) vegetation in the year 2015 to 38 km2 (11%) by the end of 2018 (Figure 3).

Glaciers are one of the major water resource in Pakistan. Glaciers in the Karkoram Mountains are surging and depict anomalous behavior (Hewitt, 2005; Minora et al 2013; Gardelle, 2012). In Shishper watershed two main glaciers are exist namely, Shishper and Mochowar glacier, and the watershed has two tongues glacier. The Shishper and Muchowar glacier was assessed by remotely sensed Sentinel-2 ESA high resolution images acquired.

Our study indicates the anomalous behavior of Shishper glacier. Spatial and temporal changes in snow, clean and debris glacier shown in Figure 4. In the month of May 2018, the stable situation was found in Shishper and Muchowar glacier. Moreover, in the month of July 2018 a dramatic movement was observed in Shishper glacier, and it collided with Muchowar Mountain and completely blocked water flow of Hassanabad Naalah. In the month of July 2018 no prominent lake was observed in the image while in the month of November 2018, a lake with an area of 0.026 km2 was noticed. Similarly, within two months (i-e from November 2018 to January 2019) a prominent lake appeared with an area of 0.057 km2. Figure 5b and 5d shows terminus of Shishper glacier and its newly formed Glacier Lake.

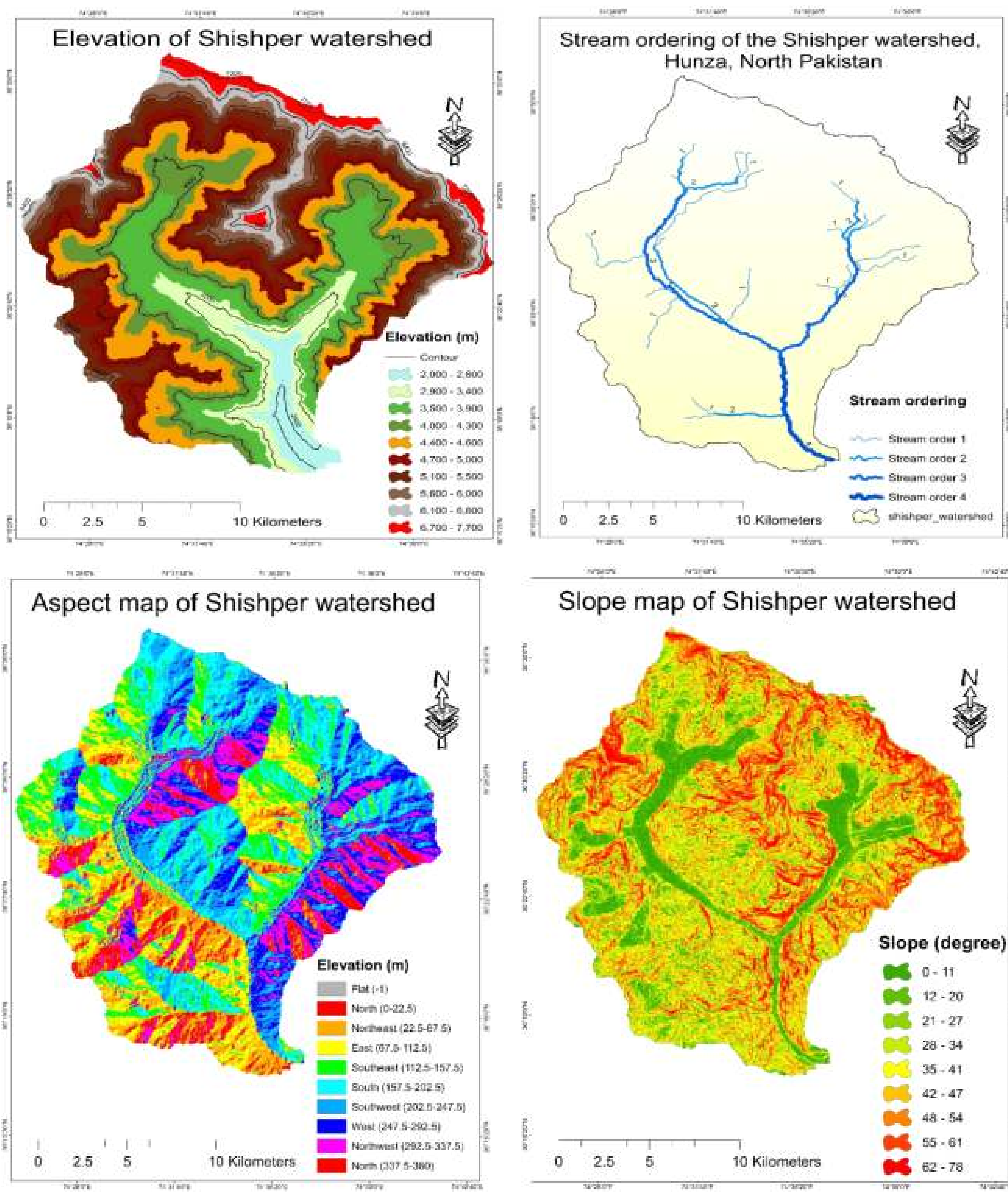

Fig. 2. Morphometric characteristic of Shishper watershed.

Table 1. Shishper watershed elevation, aspect and slope.

Elevation (m)		Aspect		Slope	
Elevation Classes	Elevation (area km^2)	Aspect	Aspect (Area km^2)	Slope (degree)	Slope (Area km^2)
2,000 - 2,800	15	Flat (-1)	0	0 - 11	27
2,900 - 3,400	25	North (0-22.5)	17	12 - 20	31
3,500 - 3,900	43	Northeast (22.5-67.5)	40	21 - 27	39
4,000 - 4,300	57	East (67.5-112.5)	47	28 - 34	51
4,400 - 4,600	57	Southeast (112.5-157.5)	52	35 - 41	56
4,700 - 5,000	47	South (157.5-202.5)	57	42 - 47	55
5,100 - 5,500	43	Southwest (202.5-247.5)	56	48 - 54	46
5,600 - 6,000	35	West (247.5-292.5)	43	55 - 61	35
6,100 - 6,600	24	Northwest (292.5-337.5)	32	62 - 78	19
6,700 - 7,700	13	North (337.5-360)	15		

Table 2. Morphometric characteristic of Shishper Watershed, Hunza, North Pakistan.

Basin area	Basin Perimeter	Drainage density	Stream frequency	Circularity ratio	Elongation ratio	Drainage texture
359(km^2)	88 (km)	0.33	0.14	0.58	4.57	4.05
Strahler stream ordering system						
1^{st} order	2^{nd} order	3^{rd} order	4^{th} order	Total streams	Stream type	
21	8	2	1	33	4^{th} order stream	

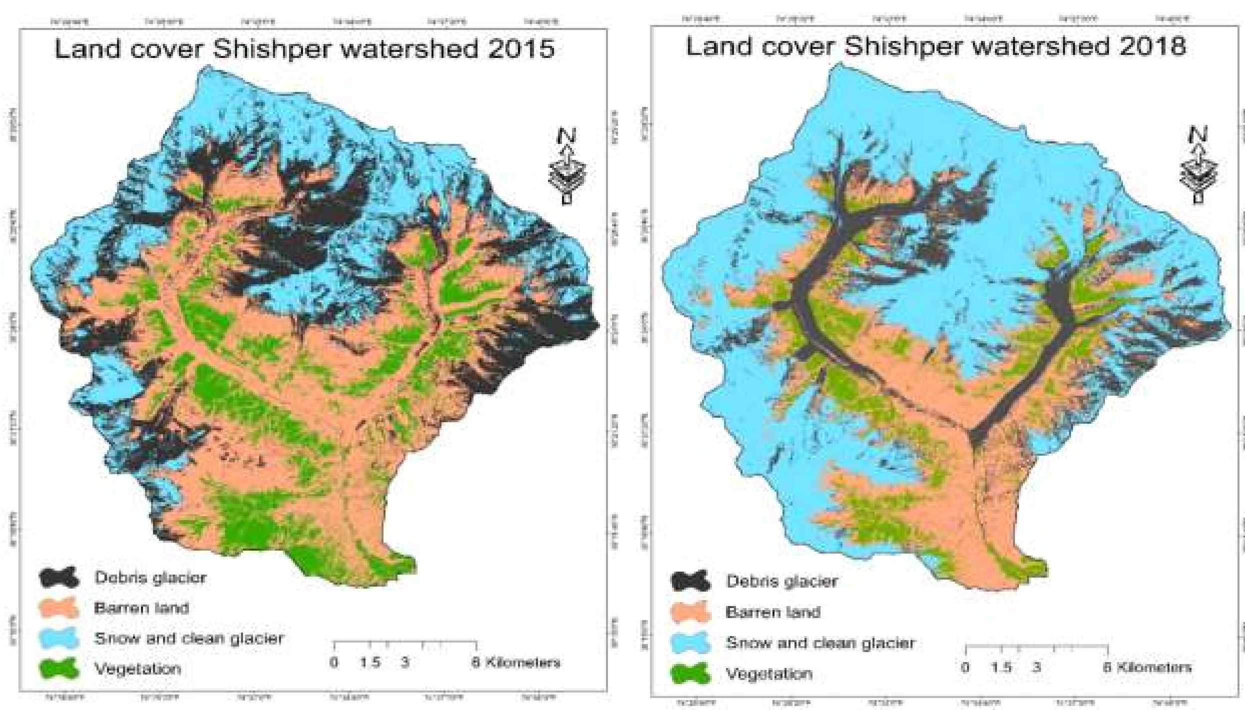

Fig. 3. Shishper watershed land cover change between 2015 and 2018.

Table 3. Land cover Shishper watershed (2015-2018).

Land cover category	Land cover (km^2) (Sept 2015)	2015 (%)	Land cover (km^2) (Sept 2018)	2018 (%)
Snow & clean glacier	97	27	123	34
Debris glacier	64	18	74	21
Vegetation	44	13	38	11
Rock and soil	144	42	124	35
Total area	359	100.00	359	100.00

Source. Generated from Sentinel-2 image 2015 and 2018

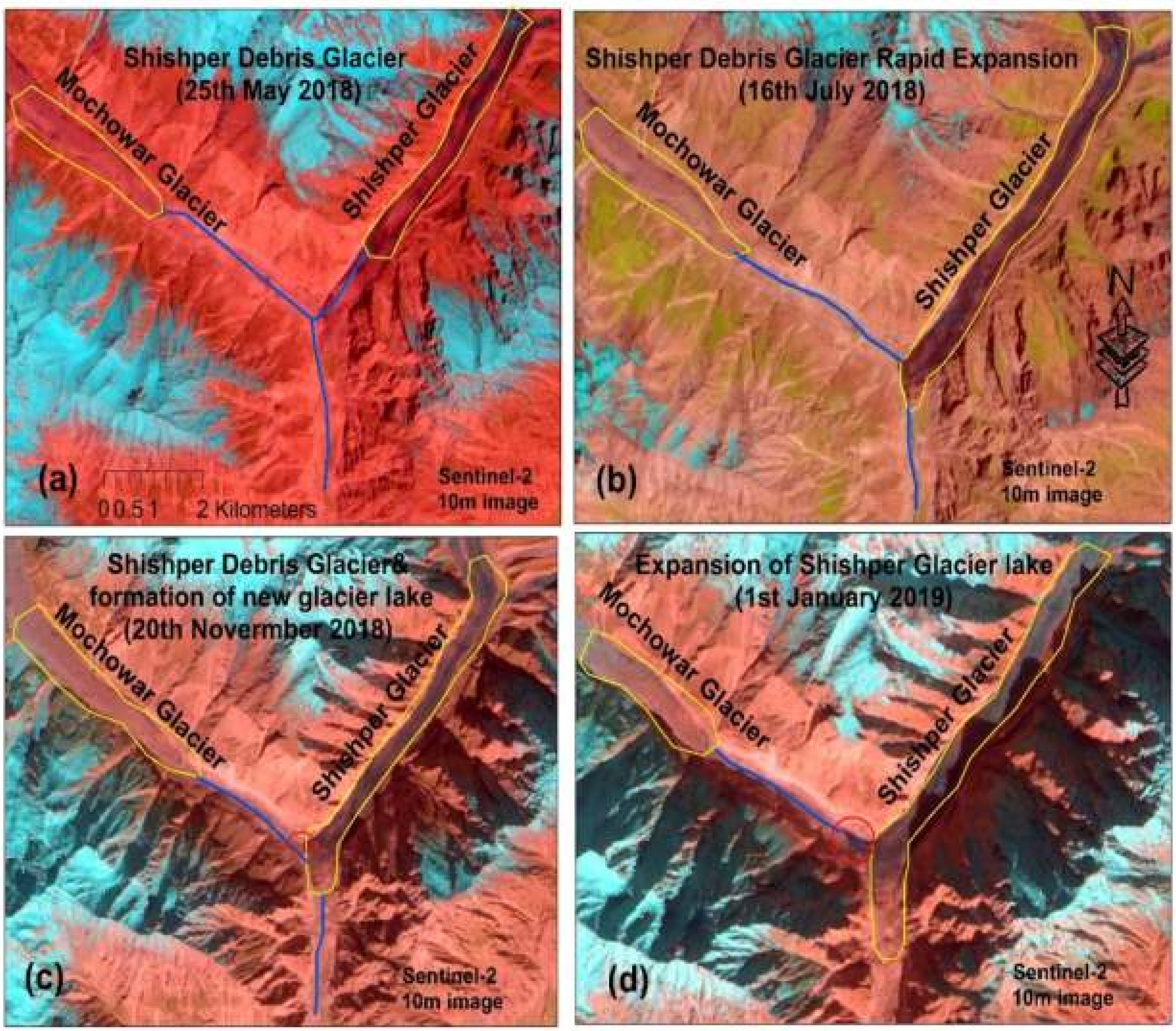

Fig. 4. Temporal analysis of Shishper glacier and Glacier Lake.

4.3. Physical vulnerability

Physical vulnerability refers to the exposure of a place towards a possible event (i.e. Lake Outburst). According to the IPCC (2012) the presence of human and natural environment, tangible and intangible assets, human activities and services, infrastructures in an area can be affected by the hazard. The physical vulnerability assessment has focused on the both sides of Hassanabad naalah (ravine). The exposure depends on physical processes and the magnitude of such an event. The finding shows Hassanabad village is highly susceptible for Shishper GLOF hazard. Figure 6 which shows the risk elements and areas, helps to infer that 100% area of the village is located in the area of GLOF hazard as well as low lying areas in the downstream are at high risk of Shishper GLOF hazard. The land use of Hassanabad village is dominated by residential buildings, farm and orchard land and power complex of power generation plants (figure 3 and 6).

Fig. 5. (a) Shows Shishper and Mochowar glacier (b) Shishper glacier debris.

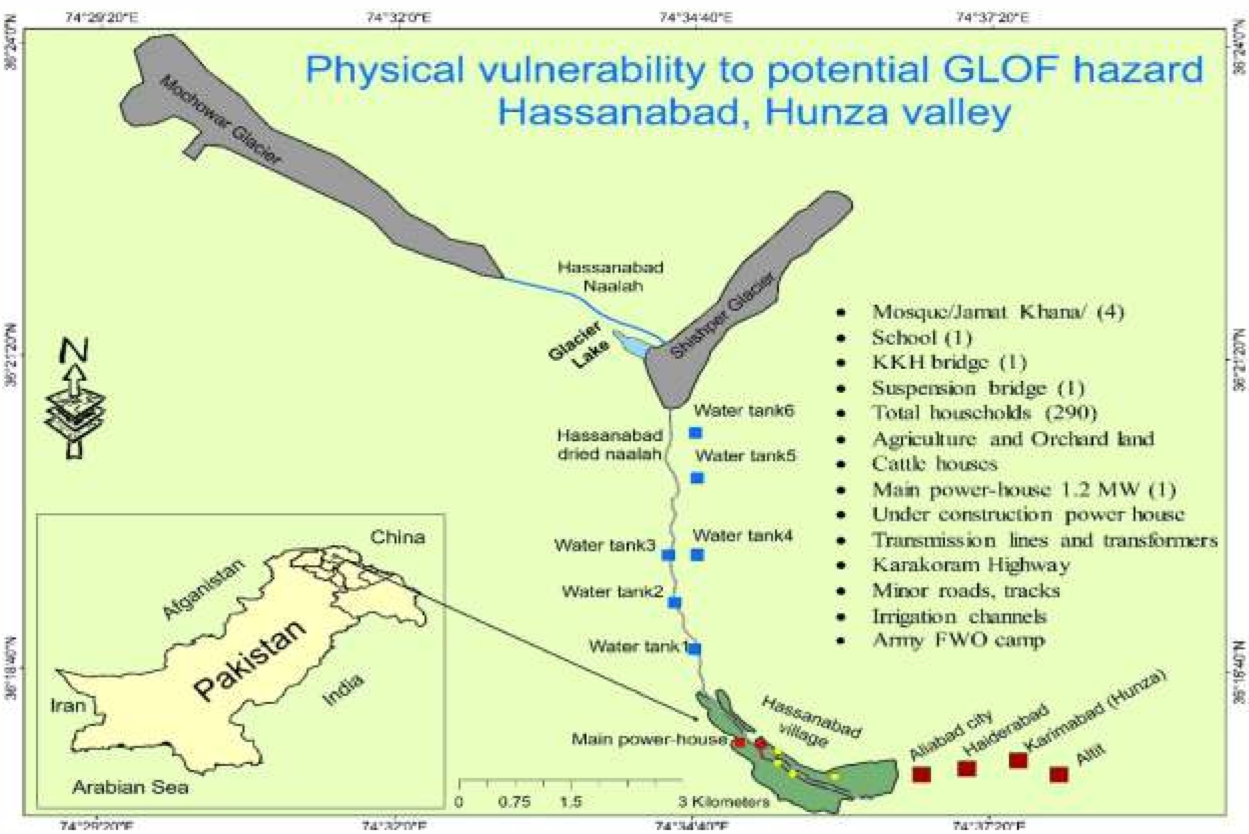

Fig. 6. Physical vulnerability map of Hassanabad village.

5. Conclusion

The Shishper basin is a sub-basin of Hunza basin in Pakistan, which covers very a large glacier system. In this study, we followed a multi-method for risk assessment of Shishper glacier and Glacier Lake using Sentinel imagery, an assessment of hazard potential of identifying lake based on high-resolution imagery, risk assessment of surging glacier based on field evidence and remote sensing data. It is inferred that the Hassanabad Naalah (Ravine) is mainly dominated by first order streams, the watershed show dendritic drainage pattern, which thus show homogeneous lithology. The majority of the streams orders are fall in first-order and then second order stream case. The watershed is designated as a fourth-order basin. The elevation ranges from 2000 to 7,700m m a.s.l. The drainage density value of the Shishper basin has a value of 0.33 km/km2 that revealing subsurface is impermeable, a characteristic feature of the high density drainage system. The circulation, elongation and drainage texture values of the basin are 0.58, 4.57 and 4.05, respectively. The results show that there is a strong structural control on drainage development. The morphometric parameters indicate that Shishper basin is a high risk basin for flash floods. The total cover area of Shishper watershed is approximately 359 km2. The results reveal a significant increase in snow cover, clean and debris glacier between 2015-2018; increasing from 161km2 to 197 km2. The land cover change analysis demonstrates that the dramatic increase in snow and glacier cover can enhance glacier related disaster risks. The analysis of remote sensing data reveals that the Shishper glacier surged in the month of July 2018 and a glacier lake has formed. The satellite observations show a significant downward movement of the Shishper glacier between July 2018 to January 2019 and lake size is increasing from 0.026 km2 to 0.057 km2. Glacier movement and Glacier Lake are expected to increase in the upcoming months due to increased summer air temperature over the basin. The physical vulnerability results indicate that more than 80% of residential buildings including property, agricultural land, hydroelectric power plant infrastructure and KKH Bridge are highly vulnerable to GLOF therefore expose to high risk. Shishper Glacier and Glacier Lake need immediate attention for GLOF risk reduction. The glacier and glacier lake risk reduction strategies should focus on (1) continuous monitoring of the glacier movement and Glacier Lake is required to avoid exposure of life, property and infrastructure in flood-prone areas; (2) establishing early-warning system in the source area, more lead time is very important in early-warning for those living in low laying areas to respond to the GLOF event; (3) reducing the current GLOF hazard through community awareness and preparedness; (4) strong cooperation among the institutions is needed for research and sharing information on the issues related glacier hazard to reduce GLOF risk; (5) national and international community must mobilize the resources for addressing GLOF issues and climate change induced disasters for the holistic disaster risk reduction.

Authors' Contribution

Attaullah shah proposed the main concept and involved in field visits, critical revision of the article and final approval of the version to be published. Karamat Ali, involved in data collection, GIS based mapping and in write up. Syed Moazzam Nizami review and proof read of the manuscript. Irfan Ullah Jan provided critical feedback and helped shape the research and contributed the final version of the manuscript. Iqtidar Hussain involved in data collection and assistance in preparation of figures. Farida begum involved in proof read of the manuscript and provided assistance in review.

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