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Risk Assessment of Attabad lake Outburst Flooding using integrated Hydrological and Geo-spatial Approach

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Abstract

Attabad Lake is a debris dammed lake in Gojal valley, Pakistan. It is likely to outburst because of the geological and hydro-meteorological settings of the region. This study is an effort to assess the Attabad Lake outburst flooding using integrated hydrological and geo-spatial approach. Both primary and secondary date have been utilized to achieve objectives of the study. The onset of such a hazard is dependent on the intensity and frequency of rainfall, the melting of glaciers, River Hunza discharge, type of soil, extent of mass movement, and the seismic activity as the region lies on an active fault line. The vulnerability of the forty-eight villages downstream can be easily assessed on the basis of various parameters of social, economic, and structural nature which include type and size of house, size of household, male to female ratio, monthly income and expenditure and the estimated damage cost. Considering the parameters of house type, occupation and access to safe place, there are around 21 villages that are highly vulnerable including Askurdas, Budalas, Chaprot, Dadimal, Garelt, Ghamadas, Guoro, Guvachi, Hakuchar, Isfahan, Jehgot, Maiun, Miachar, Minapin, Phakkar, Pissan, Rabbat, Sarat, Shayyar, Sumayyar and Thol. The exposed elements are basically divided into three categories of structural, social and economic exposure. The socially exposed elements are the household size which is an average of five persons per household. The structural elements exposed are the 48 villages and 8 bridges. The economic exposure can be gauged on the basis of monthly income which is less than PKR 30,000 for almost 80% of the population in the downstream region. In case of flooding, only the house damage cost is averaged at PKR 1,50,000 for the houses of more than 76 percent houses. The Gumbel frequency estimated the probability for 5, 10, 25, 50, 100 and 200 years. It shows that as the return period increases, the chances of flooding decreases, but there is increase in flow discharge even with the decreasing probability of occurrence of flood. The return period of 5 years has 20 percent chances of inundation. However, this decreases to only 0.5% in two centuries but with the flood discharge of 2170 m^3/s. The dam breach concludes that over 35, 46, and 63 km of the surrounding area is at risk with 10,739 m^3/s, 44,904 m^3/s and 175,145 m^3/s of flood discharge for 25, 50 and 100 percent dam breach, respectively.

1. Introduction

Lake outburst is common in the regions of elevated topography. Globally, the fraction of lake in the high-altitude region that faces the outburst is extremely high due to various factors. One of the major draw-back of such a phenomenon happening is the flooding of that region. Heavy water discharges relatively more than the channel capacity resulting in inundation of the area adjacent to the channel is called a flood (UNISDR, 2018; Mahmood, 2019). The factors may be natural or anthropogenic. The nature of flood depends on the topography of that region, the economic and industrial activities, and the mode of storage of water (Mahmood and Rahman 2019a,b). The risk of flooding of Attabad Lake will cause extreme damages to the villages near

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the lake and in the Hunza river downstream area. The significance of study lies as the water level continued to rise, and the landslide lake was formed. Due to certain factors involving the fault line, rainfall intensity, soil, and glaciers nearby, there is a great chance of outburst of Attabad Lake (Hussain et al., 2023). There's a total of 48 village's downstream Hunza River. The presence of a landslide lake really makes the native and the researchers question the safety of the downstream region and the area near the lake. A thorough examination of the area under study is required to gauge the probability of such an incident happening. In that case, there is a need for assessing the hazard and vulnerability and analyzing the risk in the area. This will provide high-risk zones and in turn help in devising the flood preparedness plan to minimize the damages in the region (Shabbir et al., 2022).

Globally, extreme weather events and physical processes lead to geomorphological changes. Land sliding is one of the geological phenomena with secondary effects like the formation of landslide dams (Khan, 2022; Gull et al., 2023). These types of lakes are short-lived due to the water pressure on the loose fragments of debris piled across the valley. Due to sudden outbursts, the water rushes from the lake and causes massive flooding (Bout, 2018). The creation of such a dam needs vast range of the physiographic settings. Rock and debris avalanches are the typical types of mass movements these result in the formation of barrier lakes (Guerrero, 2018). Rainfall and melting of snow (Paliaga, 2019), rockslides, mudslides, earthquakes and seismic motion of the earth are highly related to the landslide occurrences around the globe (Chen and Chen, 2019). Gormire Lake in Yorkshire, England is an example of such kind of lake. Sarez Lake in Tajikistan and Zalzal Lake in Pakistan was formed due to the land sliding caused by the earthquake (Shabbir et al., 2022).

The lake outburst is the sudden discharge of a lake, common in the regions of elevated topography (Hussain et al., 2023). Most landslide dams are remarkably short-lived. Overtopping is considered a typical reason for the failure of landslide-dams. They may be generated by icefalls, rock falls, or even avalanches (Husain and Hossain, 2018). The other reason can be the ice-cores melting and the seepage of frozen ground and piping. The hydrologic cycle is responsible for circulating the water throughout the environment. The balance is maintained due to this process in air, ground and on the surface. But the hydrologic cycle, sometimes face an imbalance, resulting in extreme discharge of water to an area than it can handle. This results in flooding (FEMA, 2018). Factors leading to flooding can be natural or anthropogenic. They depend on topography, economic and industrial activities, mode of storage of water and permeability of surface cover (Shabbir et al., 2022).

The flood of Noah (A.S.) also known as the Great Deluge occurred in 2348 BCE. Its area extent was current day Egypt, Lebanon, Syria, and Damascus (Young, 2008). The annual Nile River and 413 BC flood of Tiber flooding is an example. In 1913, on the Miami River, United States suffered extreme damages from river overflow. The Mississippi River overflew several times each year followed as 1927, 1937, 1973, and 2011. Huang He or the Yellow River in China has been the cause of the world's most destructive floods (Liu et al., 2019).

Pakistan is ranked 9th for flood-affected lands (Baker, 1988). In the summer of 2010, Khyber Pakhtunkhwa received around 312 mm rain. There were over 1600 deaths and 14 million people were impacted (Alderman et al., 2012). Flood-affected regions serve are the breeding grounds for pathogens that lead to the outbreaks accelerated by poor hygienic conditions of the camp that led to major epidemic break out. Diarrhea and infections of ear, lungs and eyes, malaria, and hepatitis are the examples (Leandro et al., 2022). Economic loss is extremely related to the conditions of pre-flood income. It also depends on the duration, intensity, and the type of flood.

The region can be vulnerable to floods due to the exposure, capacity, and vulnerability (Terti, 2015). Exposure simply highlights the elements to be affected like infrastructure, heritage, agricultural area, and the population (Shah and Rana, 2023). Susceptibility relates to system characteristics, including the awareness and preparedness of the population for pre-flooding risk, institutes that ensure mitigation and work for reducing the impact of hazards. Vulnerability can be defined as the elements that are exposed and influence the possibility of harm during the hazardous floods (Khan, 2022; Al-Juaidi, 2018).

Risk assessment is a combination of hazard, vulnerability, and exposure. All these combined, give us the probability of occurrence, exposed elements, and their extent of exposure to the damages of the flood (Lyu, 2019). Hazard is an interpretation of possible flooding and it depends on the type of hazard information, exposure of elements at risk and the intensity and quantity of elements to be affected including vehicles, homes, and bridges. Massive erosion by floodwaters lead to collapsing of bridges, levees, and buildings. Another effect is the water flux into the community (Hussain et al., 2023; Slater, 2016).

Risk can be stated as the probability of hazard and susceptibility (Shah and Rana, 2023). So, vulnerability studies aim to recognize the methods required to reduce the vulnerability before-hand. The vulnerability can be of four types. Physical Vulnerability is the population density level, locality of a settlement, the site and situation of the settlement, composition and materials used for infrastructure (UNISDR, 2019). The second is social vulnerability which relates to the incapability of population, and the society to cope with the impacts to hazards (Khan, 2022). Economic Vulnerability is dependent upon the economic status of the population at local, community and national level. Environmental Vulnerability is linked with the natural resource depletion and resource degradation. For instance, the Wetlands, like are sensitive to the increased salinity due to presence of seawater (Jongman et al., 2015).

Flood exposure includes assets and valuables lying in the flood prone areas from land cover to land use, from human lives to livestock and residential to agricultural trends (Cutter et al., 2000; Wu et al., 2002).

HEC-RAS is to manage the water hydraulics and channel flow analysis, management of floodplains, bridge designing and culvert analysis, channel modification research and dam breach analysis. HEC-GeoRAS is a tool for analyzing the geo-spatial data in Arc GIS by creating center line of streams, the flow-paths, the banks of channel, and XS lines. It is for mapping the flood plains, computing the flood damage, for restoring the ecosystem, warning, and preparedness of flood.

2. Study Area

Initially Attabad Lake is situated in the Gilgit-Baltistan region of northern Pakistan in the Hunza Valley, approximately 30 kilometers upstream from the town of Aliabad. The absolute location of the lake is approximately 36° 22' 0" N, 74° 42' 0" E.

The lake was formed in 2010 due to a massive landslide that blocked the Hunza River, causing it to overflow and submerge surrounding areas. It is surrounded by steep mountainous terrain, with the Karakoram Range to the north and the Himalayan Range to the south. The lake is situated at an altitude of approximately 2800 meters above sea level and covers an area of around 14.5 square kilometers. The area is also home to several glaciers, including the Batura Glacier and the Passu Glacier. The terrain around Attabad Lake is characterized by steep, rocky cliffs that rise up to 2000 meters above the water level (Kreutzmann and Watanabe, 2017).

The climate of the Attabad Lake area is subarctic, with cold temperatures and snowfall in the winter months. Summers are mild, with temperatures averaging around 20°C (Bilal, Shah, & Alvi, 2015). The area receives its highest precipitation during the monsoon season, which typically lasts from June to September.

The population is relatively small, with an estimated 6,000 people residing in the Hunza Valley, of which Attabad Lake is a part (Shakeel & Zhang, 2017). The area has seen significant development in recent years, particularly in the form of infrastructure development. The construction of the Karakoram Highway, which passes through the area, has facilitated transportation and trade between Pakistan and China (Kreutzmann & Watanabe, 2017). However, the area has also experienced significant environmental degradation as a result of this development.

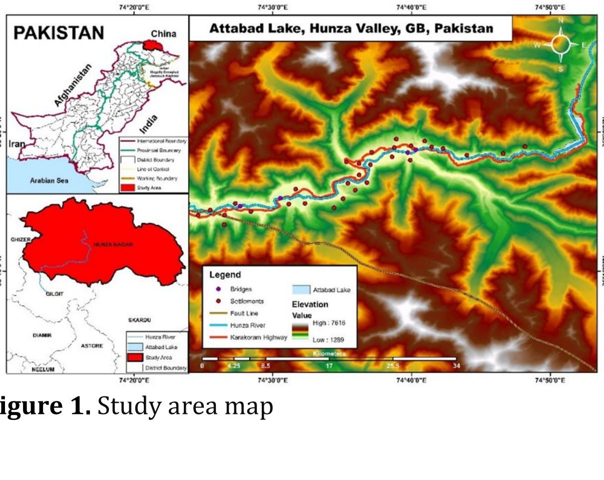

Figure 1. Study area map

3. Research Methodology

3.1. Data Sources

The data utilized for this research was of both primary and secondary nature. The main source for the data collection were the websites and open data sources for the acquisition of satellite images, Digital Elevation Model, precipitation data and fault line maps. Also, there were questionnaire surveys on call. The data has been remotely gathered.

Satellite images have been downloaded from Sentinel-hub and USGS Earth Explorer. The pre-landslide of Attabad lake area has been acquired from Landsat 7 for the year 2010 and for the post landslide and the current conditions, Sentinel 2 image has been used for the year 2019.

The Digital Elevation Model used was PALSAR (Phased Array type L- band Synthetic Aperture Radar). ALOS PALSAR DEM has been downloaded from the data search vertex of NASA that is the Alaska Search Facility through the website search.asf.alaska.edu. It for the date 12 February 2007 with a resolution of 12.5 meter. PALSAR DEM was preferred due to its capability of capturing the minute precise details of weathers and all times of the day and the night. It also has repeat-pass interferometry.

The precipitation and discharge data have been acquired from climate-data.org. WAPDA online and Grains Research and Development Corporation data (GRDC) sources has been used to acquire the average annual discharge data.

The data preparation was performed by image processing at first. Stacking was done and then digitization was done. The features digitized include the Hunza River as a line feature. Attabad Lake and the villages of Hunza and Nagar district that lie on the downstream of Hunza River as the polygon feature. The Karakoram highway is digitized using the Open Street map. The co-ordinates of bridges have been attained from Google Map. Supervised classification was performed that included Built-up area for which a total of 104 training samples were taken, 236 for the river Hunza, 97 for barre land and 125 for the vegetation class. It used for the calculation of the area under flood. The area field was added, and the geometry was calculated. The area parameter was selected, and the calculated aspects were the land under flood in square kilometers (sq. km.) and, percentage. The result was added in form of inundated map and graphs.

Watershed modelling is done to delineate the stream network originating to or from a water body, specifically performed by calculating Digital Elevation Model as the main input.

The hydrological modelling has been done using the HEC-GeoRAS 10.3 extension in ArcGIS 10.3.1. The main application of this modelling lies in creating Hunza river center line, the left bank, the right bank of the river and the two flow paths on both the sides of River Hunza. The DEM has been used in grid format. A total of 168 XS-lines were generated with the interval of 1km for a 60 km long river channel. The cross-section width was 1500 meters with 500 meters apart. At last, the data was exported through Extract GIS data under the RAS Geometry that was used afterwards as the input for the HEC RAS software.

The Hydraulic modelling was performed by using the HEC-RAS 5.0.7 software. The input data was basically the output values generated as a result of the hydrological modelling done in HEC- GeoRAS 10.3. Manning's values are then set as 0.05 for the study area (Mahmood et al., 2009). For, Steady flow analysis, discharge values have been added as PF values. Reach boundary conditions are assigned for the downstream and upstream. Then, the steady flow simulation is run, and the computation is saved. From RAS mapping, the Inundation mapping is selected to generate Water Surface on basis of PF1 that represent the discharge values. The Floodplain delineation using Raster is done through RAS mapping.

The Gumbel frequency distribution is a technique for modelling the distribution of samples which can be large in number, based on their maximum or minimum distribution. The frequency is applied on the provided range of the values. The model than calculate the probability on the values. This technique was applied on the annual Hunza river discharge values from 1978 to 2020 for a time of almost 4 decades. The flood probability has been acquired for 5, 10, 25, 50, 100 and 200 years.

4. Results

In The risk assessment of flooding is crucial particularly in the mountainous area where the floods are mostly flash floods. The possibility of occurrence, elements at risk and their exposure are the main indicators of assessing the damage. Hazard assessment shows us lake volume, the factors causing possible flooding. Vulnerability is the measure of the socio-economic, housing, and safe place access. These two merges to present the elements at risk and provide a picture of the risk of that area. Community perception is a vital aspect in understanding the risk. This research aims to cover all the three aspects of risk assessment of flooding in Attabad lake including the hazard, vulnerability and exposed elements.

4.1. Socio-economic Characteristics

4.1.1. Female Population

The maximum frequency is followed by more than 2 female members per household in 25 villages making up about 52% of the total exposed population of the female society. Such households must be considered highly exposed and vulnerable.

Table 1. Average Number of Females Per Household

Serial No.	Females	Frequency	Percentage
1	< 2	2	4.16
2	2	21	43.75
3	> 2	25	52.08

(Source: Questionnaire survey, November 2020)

4.1.2. Disabled Population

Askurdas, Shayar, Hakuchar, Ghamadas, Phakkar, Miachar, Minapin, Rabbat, Chaprot, Budalas and Guvachi have zero percentage of disabled people. Whereas the village of Sultanabad is at the highest risk of vulnerability on basis of disability of about 5% of its population. 12 out of 48 villages are at medium vulnerability scale. The number of villages at the lowest venerable scale are twenty-four.

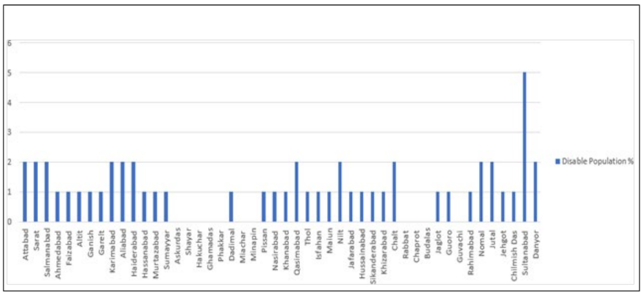

Figure 2. Showing The Percentage of Disabled Population in The Villages Along River Hunza Downstream Channel.

4.2. Housing Conditions

The Kacha and Semi-Pucca houses are in an average of 9 villages each, making up 18 villages overall and contributing to the total of 36% of settlements. The Pucca houses are present in only 30 villages, making up about 62 percent of the total category in the 48 villages under study.

This means that the frequency of the exposed type of houses are total 18 for Kacha and semi-pucca house and 62 for villages with pucca houses.

Table 2. Type of Houses

Serial No.	House type	Frequency	Percentage
1	Kacha	9	18.75
2	Semi-Pucca	9	18.75
3	Pucca	30	62.5

4.3. Map of Distance to Stream

The graph is a representation of the public observation and experience regarding the presence of a safe area in case of flooding. It is eminent that the ratio is extremely close to the most and the least vulnerable areas. The number of villages with the population having the perception that there is no safe place for refuge in case of flooding are 23 and the rest of the 25 villages have a safe place to go to which is either an upper area or the community hall.

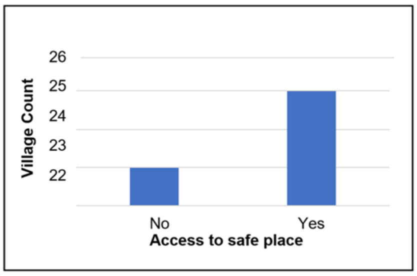

Figure 3. Access to Safe Place

4.4. Hazard Assessment

4.4.1. Factors

4.4.1.1. Precipitation

The average rainfall in the Hunza-Nagar district is 136.2 mm (Afsar et al. 2013; Qureshi et al. 2017). The precipitation in maximum in the months of spring season from March to May. These generally contribute to a significant rise in the water level of the channels and streams. The increased level of waters can be observed in the Hunza river, too (Gadiwala and Burke, 2019).

4.4.1.2. Glacier

Batura, Passu, Ghulkin, Hussaini, and Gulmit glaciers have their melt in the Hunza river. These receding glaciers also pose a threat to the flow volume of the river as many streams from these glaciated mountains flow into the Hunza river channel particularly in the downstream area (Shah and Rana, 2023; Minora, 2016).

4.4.1.3. Fault Line

The Main Karakoram Thrust and the Main Mantle Thrust lies right below the district boundary of Hunza-Nagar and Gilgit (Ali et al., 2019). So, the area experiences the earthquakes of unfelt frequencies almost every day. This situation undoubtedly makes the region under study, extremely prone to the threat of flooding (Bacha, 2018).

4.4.1.4. Stream Network

The accumulation and confluence of small streams is the most in the Attabad lake region. This leads to a higher probability of water inflow in the lake. Resultantly, the outflow will be maximum.

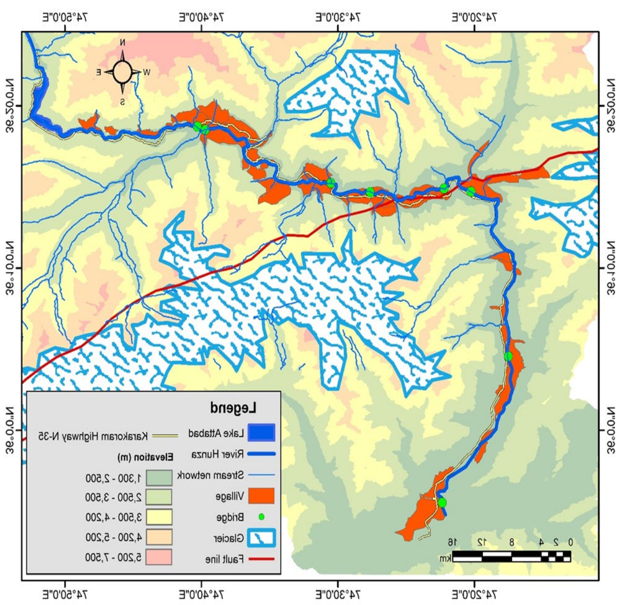

Figure 4. Flood Hazard Map

4.4.2. Lake Volume

The dam breach has been calculated and performed for the scenario including a hundred percent total failure of the landslide dam (Chen et al., 2016). The discharge of 100% of the dam breach is 175,145 m^3/s, respectively.

Table 3. Dam Breach

Breach scenario	Upstream water depth before breach (m)	Average breach width (m)	Dam site maximum discharge Q (m^3/s)
Total failure	100.0	283	175,145

4.4.3. Dam breach

The dam breach has been calculated and performed for the scenario including a hundred percent total failure of the landslide dam (Chen et al., 2016). The discharge of 100% of the dam breach is 175,145 m^3/s; inundating an area 63 kilometers with 3150 km^3 flood volume with the mean depth of 50 meters, respectively. The total inundated area is calculated to be 14 km in which the built-up area will 1.69 sq. km making up almost 12% of the total inundated area, vegetation makes up about 3 km (21%), barren area about 5 km (38%).

4.5. Vulnerability Assessment

The Socio-economic characteristics include the 25 villages making up about 52% of the total exposed population of the female society by more than 2 female members per household in. Such households must be considered highly exposed and vulnerable. Considering the disabled population, 12 out of 48 villages are at medium vulnerability scale. The number of villages at the lowest venerable scale are twenty-four. Sultanabad is at the highest risk of vulnerability. The Kacha and Semi-Pucca houses are in an average of 9 villages each, making up 18 villages overall and contributing to the total of 36% of settlements. The Pucca houses are present in only 30 villages, making up about 62 percent of the total category in the 48 villages under study. This means that the frequency of the exposed type of houses are total 18 for Kacha and semi-pucca house and 62 for villages with pucca houses.

4.6. Risk Assessment

The risk assessment done through hazard, vulnerability and exposure analysis show the extent of elements that may fall under the destructive dam breach of Attabad lake. It can easily be identified that the elements in the close proximity are the most vulnerable and are at a high risk. The imminent danger of destruction reduces as the distance from Hunza river increases but it does not eliminate the risk on the whole. The assessed risk for the settlement, bridges and Karakoram Highway shows the risk of being flooded provided the flow discharge of a complete dam breach.

This also gives a way forward to devise ways to prepare, prevent and mitigate the expected flooding in the study area.

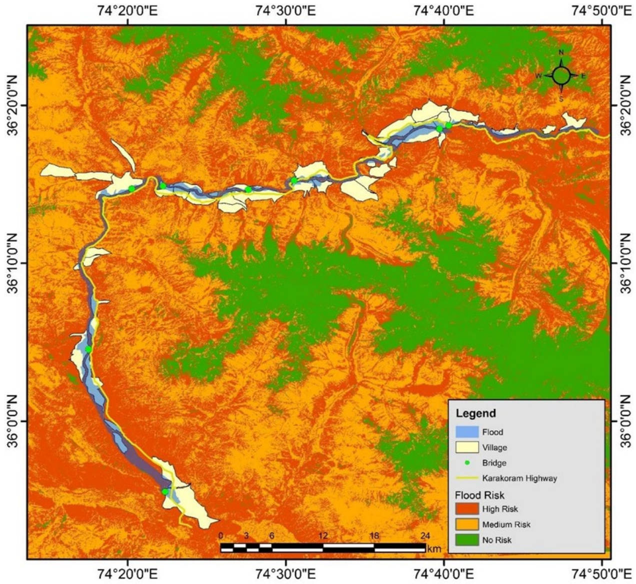

Figure 5. Flood Risk Map.

4.7. Risk Perception

The total extent of flood will be 63 km and the destruction to nearby human settlements will be around 14 km. There are 40 villages in the downstream region and most of them faces an imminent hazard. The local means of communication are the bridges, and all the 8 bridges will be destroyed along with the Karakoram Highway (N-35) that is the major land route to connect Pakistan to China.

The district of Gilgit is more at risk than the Hunza district because the elevation drops, and the flood flow will have a great pressure due to gravity. The areas of much focus in Hunza district are those linked to Karimabad and the villages that lie closer to the Attabad Lake. The medium risk zones have lesser parts of villages in it, but this does not eliminate the chances of flood destruction here. The no risk zones are basically barren as it mainly contains the snow-covered area. But this no risk zone can be a cause of hazard as streams and narrow water channels flow from it in the summer season. Above all, the downstream area is at the greater risk of flooding and this situation needs to be catered.

5. Discussion

Risk Assessment of Attabad lake outburst Flooding using integrated hydrological and Geo-spatial Approach aims at finding the major causes for the outburst and then its repercussions. The research focuses on the assessment of the extent of exposure of various elements to the hypothetical outburst flooding of Attabad lake for providing ease to future preventions and risk management policymaking. The study focusses on the estimation of financial loss and the marking of safe zones for the natives to move to in case of flooding. To achieve the objectives, different kinds of analysis will be performed including the descriptive, statistical, correlative analysis, depth analysis, and the change detection analysis. The research will use the base-map and images provided by will also acquire Sentinel I & II satellite images having a resolution of 10 meters. PALSAR Digital Elevation Model will be used for watershed modeling. Similarly, the same data will be used to model river geometry. This imagery data will help in producing the Geographic Information System (GIS) layers that will show the extent of the outburst flood on the surrounding area. Digital Elevation Model (DEM) will be used to determine the outburst geometry of the lake and to further explain the exposed sites for the lake outburst flooding. Hydrologic Engineering Centre's River Analysis System (HEC-RAS) (Butt, 2012) and Hydrologic Engineering Centre's Geographic River Analysis System (HEC-Geo-RAS) will aid in creating and gauging the extent of the exposed area to Attabad Lake outburst flooding (Elena Shevnina, 2019) approach. Gambol's modelling technique will provide a probabilistic approach. The spatial modelling will then be done to present the outcome of the research (Mahmood et al. 2019). On the whole, the practiced techniques will be that of GIS, Remote Sensing and Global Positioning System (GPS). Further, a questionnaire survey will be done to know about the community perception and to gauge the capability of the natives to cope up with the predicting hazard. The areas with a relatively large population will be considered along with the residentials region near the banks of the lake.

The research on flood risk assessment of Attabad lake outburst concludes that the downstream region of River Hunza faces an eminent danger of inundation. It is evident that around 5 km buffer area is extremely exposed to the calculated flood discharge. Considering the survey, parameters of house type, occupation and access to safe place, there are around 21 villages that are highly vulnerable including Askurdas, Budalas, Chaprot, Dadimal, Garelt, Ghamadas, Guoro, Guvachi, Hakuchar, Isfahan, Jehgot, Maiun, Miachar, Minapin, Phakkar, Pissan, Rabbat, Sarat, Shayyar, Sumayyar and Thol. The dam breach has been calculated and performed for the scenario including a hundred percent total failure of the landslide dam (Chen et al., 2016). The discharge of 100% of the dam breach is 175,145 m^3/s; inundating an area 63 kilometers. The total inundated area is calculated to be 14 km in which the built-up area will be 12% of the total inundated area, vegetation makes up about 3 km, barren area about 5 km also posing a great threat to the Karakoram Highway that accounts for more than 70% of Pakistan and China's annual trade. The socially exposed elements are the household size which is an average of five persons per household, the male and female members around an average of two per household are 58 and 43 percent, respectively. The structural elements exposed are the 48 villages and 8 bridges, and around 36% percent of the villages have semi-pucca and Kacha houses while 30 villages have pucca house with 62% of the total community under study. The economic exposure can be gauged on basis of monthly income which is less than PKR 30,000 for almost 80% of the population in the downstream region, with around 70% of the population associated with the business-based earning setup. The monthly expenditure is around PKR 30,000 for 58 percent of the population leaving no margin for savings of profit. In case of flooding, only the house damage cost is averaged at PKR 1,50,000 for the houses of more than 76 percent houses and the rest estimate the cost of above the average cost for their residential needs. The downstream area of River Hunza has more than 40 villages that are spread in the Hunza-Nagar and Gilgit district of Gilgit Baltistan. The river follows the downstream path for about 60 km into the valley. The surrounding villages and settlement are populated with people related to business and agriculture mostly. The area in the vicinity of less than five kilometers is considered extremely prone to flooding. The people here are always conscious about the inflow and outflow of water and the discharge that follows itself into the river during the glacial melt, or rainfall season. Also, the watershed delineation shows that River Hunza gets the water input from more than 30 streams and small but rapid water channels throughout its course in the downstream region. The accumulation and confluence of small streams is the most in the Attabad lake region. This leads to a higher probability of water inflow in the lake. Resultantly, the outflow will be maximum.

The strength of this research lies in the fact that the water level continued to rise and fall a bit. Due to certain factors involving the fault line, rainfall intensity, soil, and glaciers nearby, there is a great chance of outburst of Attabad Lake. There is a total of 48 village's downstream Hunza River. Most of the villages are less than even five kilometers in expansion and they face a great danger of inundation in case of flooding. In that case, there is a need for assessing the hazard and vulnerability and analyzing the risk in the area. This will provide the high-risk zones and in turn help in devising the flood preparedness plan to minimize the damages in the region.

6. Conclusion

The research on flood risk assessment of Attabad lake outburst concludes that the downstream region of River Hunza faces an eminent danger of inundation. The onset of such a hazard is dependent on the intensity and frequency of rainfall, the melting of glaciers and the overall discharge in the Hunza river. It is evident that around 5 km buffer area is extremely exposed to the calculated flood discharge. The vulnerability of the forty-eight villages under study can be easily assessed on the basis of various parameters of social, economic, and structural nature. They include type and size of house, size of household, their male and female ratio, the monthly income and expenditure and their ability to cope with the estimated damage cost. Considering the survey, parameters of house type, occupation and access to safe place, there are around 21 villages that are highly vulnerable including Askurdas, Budalas, Chaprot, Dadimal, Garelt, Ghamadas, Guoro, Guvachi, Hakuchar, Isfahan, Jehgot, Maiun, Miachar, Minapin, Phakkar, Pissan, Rabbat, Sarat, Shayyar, Sumayyar and Thol.

The dam breach has been calculated and performed for the scenario including a hundred percent total failure of the landslide dam (Chen et al., 2016). The discharge of 100% of the dam breach is 175,145 m^3/s; inundating an area 63 kilometers with 3150 km^3 flood volume with the mean depth of 50 meters, respectively. The total inundated area is calculated to be 14 km in which the built-up area will 1.69 sq. km making up almost 12% of the total inundated area, vegetation makes up about 3 km (21%), barren area about 5 km (38%) also posing a great threat to the Karakoram Highway that accounts for more than 70% of Pakistan and China's annual trade.

The socially exposed elements are the household size which is an average of five persons per household, the male and female members around an average of two per household are 58 and 43 percent, respectively. The structural elements exposed are the 48 villages and 8 bridges, and around 36% percent of the villages have semi-pucca and Kacha houses while 30 villages have pucca house with 62% of the total community under study. The economic exposure can be gauged on basis of monthly income which is less than PKR 30,000 for almost 80% of the population in the downstream region, with around 70% of the population associated with the business-based earning setup. The monthly expenditure is around PKR 30,000 for 58 percent of the population leaving no margin for savings of profit. In case of flooding, only the house damage cost is averaged at PKR 1,50,000 for the houses of more than 76 percent houses and the rest estimate the cost of above the average cost for their residential needs.

The downstream area of River Hunza has more than 40 villages that are spread in the Hunza-Nagar and Gilgit district of Gilgit Baltistan. The river follows the downstream path for about 60 km into the valley. The surrounding villages and settlement are populated with people related to business and agriculture mostly. The area in the vicinity of less than five kilometers is considered extremely prone to flooding. The people here are always conscious about the inflow and outflow of water and the discharge that follows itself into the river during the glacial melt, or rainfall season. Also, the watershed delineation shows that River Hunza gets the water input from more than 30 streams and small but rapid water channels throughout its course in the downstream region. The accumulation and confluence of small streams is the most in the Attabad lake region. This leads to a higher probability of water inflow in the lake. Resultantly, the outflow will be maximum.

Recommendations is a two-phase process. One is prevention and it can be done through installation of water level sensors, spillways should be made in the upstream area, building an artificial dam behind the landslide debris, shifting the residential and agricultural area to higher lands, plantation on the slopes should be done to increase infiltration, river channel should be widened to reduce the pressure of flow, constructing the bridges higher than the recorded flood peak and by discouraging the use of land for built-up and agriculture in the flood risk zones. The next step is preparedness done by establishing the safe sites, planning for emergency evacuation, training the communities for First aid response, advancing the systems for an early flood warning, installing water level gauges at different points in the river, constantly monitoring the water level sensors and the upstream discharge values.

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Author contributions

Dr. Shakeel contributed largely in the formulation of the questionnaire for the on-site survey and methodology. However, due to the strictness of COVID-19 lockdown, the survey was conducted on-call. Also, he did the analysis of flood frequency through Gumbel frequency. The rest of the analysis and the on-call survey were done by Siddra Noor.

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Conflicts of Interest

The authors are on one page considering all the aspects of the research. There was no conflict of interest, on the whole, throughout the research.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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Appendixes

Questionnaire

RISK ASSESSMENT OF ATTABAD LAKE OUTBURST FLOODING

by Siddra Noor, GCUL – Supervised by Dr. Shakeel

Questionnaire Number:____________________________
Village: ____
District: ____

This questionnaire is a part of research work of Miss. Siddra Noor, a student of Department of Geography – GC University, Lahore. Your co-operation will be really a great favor that will help the progress of the society.

Purpose:

- It is necessary for the completion of the student’s thesis regarding the outburst flooding of Attabad Lake.
- It will help in collecting the data related to the exposed elements of the society to the flooding.
- It will aid the policy making departments in executing the safety and management policies to the region.

Basic Information

- Name ____
- Gender of the respondent Male ☐ Female ☐ Other ☐ Specify: ____________
- Marital status Single ☐ Married ☐ Widow/Widower ☐
- Number of family members _________
- Number of Active (earning) members _________

Females ________ Males ________

Age	**Gender**	**Education**								
-	-	Illiterate	Primary	Middle	Secondary	Inter	Graduate	Post graduate	Professional degree	Technical education

- Type of family Single ☐ Joint ☐
- Language ______________________________
- Do you have any disabled family members with you?

Yes ☐ No ☐

- If yes, how many? ____________

Females _________ Males __________

Residence

1. Are you a local or migrated?

Local ☐ Migrated ☐

2. If migrated, what was the area of emigration?

____

3. What was the reason of your migration?

____

4. In what type of house do you live?

Pucca ☐ Kacha ☐ Semi – pucca ☐

5. Ho long have you been living here (year): ________________________
6. Construction Material: ______________________________________
7. House storey: Single ☐ Double ☐ Triple ☐
8. Number of rooms: ____
9. Age of building: ____
10. Size of plot (Marla): ___________________________
11. Land use value of building: _______________________________________
12. Is your house personal, mortgaged or rent?

Personal house ☐ Mortgage ☐ Rent ☐

13. If tenant, how much is the rent? ________________

Occupation

14. What is your occupation? ______________________________________
15. Do you have any side business?

Yes ☐ No ☐

Mention: ____________________________________

16. Monthly Income: ______________________
17. Total Expenditure: ______________________
18. What are the months of maximum profit?

February – May ☐ June – September ☐ October – January ☐

Commute

19. What is the mode of your commute to work?

On foot ☐ Bike ☐ Car ☐ Public transport ☐

20. Do you own a personal vehicle?

Yes ☐ No ☐

21. If yes, which one _____________________________
22. If Public, how often do you use it? (per day/ per week/per month)

Less than twice ☐ More than twice ☐

Flood in Attabad Lake

23. Were you present during the 2010 Attabad landslide?

Yes ☐ No ☐

24. Do you think Attabad Lake can outburst?

Yes ☐ No ☐

25. If yes, what can be the cause? ____
26. If yes, do you think it will harm your house/ occupation/ property in any way?

Yes ☐ No ☐

27. According to you, what kind of dangers lie to your house/ occupation/ property?

____

Flood Risk Assessment

1. If flood hit your property, what will be the rehabilitation cost (PKR);
   - Partial damage: 1 Wall ______________ 1 Room _______________
   - Complete damage ____________________________

2. Do you have a safe place to move in case of flooding?

Yes ☐ No ☐

3. How far is it from your institution/ building?

Distance (km/m): __________________
Time (minutes/ hours): ______________

4. Is there a medical facility near your house?

Yes ☐ No ☐

5. Do you have any suggestions you believe would help mitigate the flood issues?

____

6. How often there is a flood?

Once a month ☐ Once every three Month ☐ More in winters ☐ More in summers ☐

7. How often there is a land sliding in your area, or near by area?

Once a month ☐ Once every three months ☐ Once in a year ☐

8. How close is your home to the river channel?

Distance (km/m): ______________

9. Do you ever feel unsafe living in this area regarding the danger of flooding?

Yes ☐ No ☐

10. What is your primary source of everyday water? ____________________________

11. Do you any livestock?

Yes ☐ No ☐

12. How many cattle do you have?

Mention: ____

13. How much land do you own for agriculture? ____________________________

14. Do you use the river water for irrigation?

Yes ☐ No ☐

15. Which type of crop do you grow there?

Mention: ____

Thank you for your cooperation.

Any addition or suggestions:

____
____