Mapping and modelling of glacial lake outburst flood (GLOF) of Deran glacial lake, Ishkoman Valley, Ghizer District, Pakistan using GIS and remote sensing

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Abstract. Northern part of Pakistan hosts world's largest glaciers and peaks in HKH region. These natural resources are not only a priceless source of livelihood for the local people but also poses various threats due to different phenomena like avalanches and glacier lake outburst floods (GLOF). Global warming, climate change and human activities are major factors that causes the melting of these glaciers as a result glacier recedes and develop lakes that raises water levels in downstream water ways. Such glacier lake outburst floods are one of the major disasters in these mountain regions. In this study, GLOF assessment and mapping was conducted using GIS and Remote Sensing techniques with ground truthing. Change detection technique like NDWI was performed on Landsat imagery for last two decades and flood modeling was executed using HEC-RAS based on ground data and RS. Temporal change in lake volume was increased to 60% which was calculated using surface volume tool in ArcGIS. Lake area has been extended to 31.18 % whereas ice and Glacier cover has been receded from 42.62% to 21.91%. GLOF modelling for two scenarios shows number of critical and priority infrastructure at risk like bridges, transformers, community centre, school, houses and agriculture land. The outcomes of the study will provide the base for the development of community preparedness plans and safety strategies with risk reduction measures.

Key words: *Deran, Gilgit Baltistan, GLOF, HKH, HEC-RAS, GIS, NDWI*

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Картографирование и моделирование прорыва ледникового озера Деран (долина Ишкоман, округ Гхизер, Пакистан) с использованием ГИС и данных дистанционного зондирования

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Аннотация. В северной части Пакистана находятся крупнейшие в мире ледники и высочайшие вершины региона Гиндукуш-Гималаи. Эти природные ресурсы являются не только бесценным источником заработка для местного населения, но и создают различные угрозы, связанные с такими опасными природными явлениями, как лавины и прорывы ледниковых озер (GLOF). Глобальное потепление, изменение климата и деятельность человека являются основными факторами, вызывающими таяние этих ледников и, как следствие, их отступание, что в свою очередь приводит к формированию озер, прорыв которых приводит к резкому увеличению уровня воды в реках ниже по течению. Такие паводки, формирующиеся в результате прорыва ледниковых озер, являются одним из основных бедствий в данных горных регионах. В настоящем исследовании оценка и картографирование прорывов ледниковых озер были проведены с использованием методов ГИС и дистанционного зондирования с последующей верификацией полевыми наблюдениями. Методика обнаружения изменений, например, NDWI, была выполнена по снимкам Landsat в течение последних двух десятилетий, а моделирование паводков проводилось с использованием программы HEC-RAS на основе наземных данных и данных дистанционного зондирования Земли. Временные изменения объема озера достигали +60%, что было рассчитано с помощью инструмента «Surface Volume» в ArcGIS. Площадь озер увеличивалась до 31,18%, в то время как ледяной и ледниковый покров уменьшился с 42,62% до 21,91%. Моделирование GLOF для двух сценариев показывает количество критически важных и приоритетных объектов инфраструктуры, подверженных риску, таких как мосты, трансформаторы, общественный центр, школа, дома и сельскохозяйственные угодья. Результаты исследования послужат основой для разработки планов по подготовке местных жителей и стратегий безопасности по снижению риска.

Ключевые слова: *Деран, Гилгит-Балтистан, прорыв ледникового озера, регион Гиндукуш-Гималаи, программа HEC-RAS, ГИС, нормализованный разностный индекс воды (NDWI)*

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Introduction

The northern areas of Pakistan are hosting some of the world's largest and famous mountain ranges including Himalayas, Karakoram and Hindukush (HKH). These ranges contain over 5000 snow laden glaciers that supply huge volume of water through 10 sub basins and other various tributaries that feed the mighty Indus. The ICIMOD's glacier inventory developed in 2005 using remote sensing and geographical information technologies identified that the nature and health of the HKH glaciers are changing year by year due to change in temperature and climate, these variations resulted in melting of centuries old glaciers and lead to formation of lakes in glacier's lap, there are over 2000 glacier lakes and among them 52 glacier lakes are considered to be dangerous enough to cause glacier lake outburst floods for communities living in low lying areas in the HKH region [*Rasul, 2015*].

The GLOF events are catastrophic as huge loads of debris and mud flows in the downstream sweeping the infrastructure, houses and croplands even in scores of life losses if they happen without any alert signal. For mountain population, GLOF is a great hazard which has been reinforced by climate change in terms of frequency and vulnerability in Gilgit-Baltistan region. UNDP in 2007 reported that in Gilgit-Baltistan the frequency of glacier lake outburst floods is higher as it has been recorded over 30 disaster events in last two centuries. Such disasters include the GLOF events occurred in Gupis valley during 1994, when a GLOF blocked the Ghizer river and river blockade formed a huge lake, this event took five lives and damaged livelihoods and properties of population living in downstream. Another event in 1999 in the same extent lead to form a current famous lake i.e. Khalti lake. Similar events of various intensity have occurred during 2007, 2008 and 2009 from Ghulkin glacier [*PMD, 2016*]. GLOF events are also common in Shimshal valley, as it hosts few of the largest glaciers like Khurdopin and Virjirab glaciers. One of GLOF events in 2017 has inundated the low-lying hamlets in Shimshal Centre, Aminabad and Farmanabad and damaged road, bridges and crop land. Analysis of lake through satellite images revealed that the flood was result of Khurdopin glacial lake outburst, which is a frequent phenomenon in the valley. Similar events were occurred in Passu during 1985 and 2009, Yarkhun Lusht in 2002, Brep in 2005, Sonoghore in 2007 and Booni in 2010. Baibary Lake in Hinarchi glacier Bagrot valley generated a significant flood in May 2014 and damaged the link bridge over Bagrot River near Sat village when it burst due to warm weather sustained more than seven days with clear sky conditions. Datochi Glacier and Bilchar glacier located in Bagrot valley generated outburst floods in July-August 2015 triggered by monsoon downpour with lighting/thunderstorm and caused huge erosive damage to agricultural land, link roads, suspension bridges and human settlements along the channel. GLOFs from Ghulkin glacier, Gojal valley in upper Hunza has also followed the similar mechanism in the past with the frequency of 5 outbursts in year 2008 [*FOCUS, 2013*].

Table 1. Historical GLOF events in Gilgit Baltistan

Event Year	**GLOF Location**	**River**
1994	Sosot/Gupis	Gilgit
1999	Khalti/Gupis	Gilgit
2000	Shimshal	Hunza
2000	Kand/Hushe	Indus
2005	Sosot/Gupis	Gilgit
2007	Ghulkin	Hunza
2007	Passu	Hunza
2008	Ghulkin	Hunza
2008	Ghulkin	Hunza
2008	Ghulkin	Hunza
2008	Ghulkin	Hunza
2009	Ghulkin	Hunza
2012	Sosot/Gupis	Gilgit
2017	Khurdopin	Shimshal

Source: Archer 2001, UNDP 2007, NARC 2008, Pamir Times June 2008. FOCUS, 2012

The analysis of GLOF event has revealed that the events were linked with rise in temperature and high intensity rainfall along with human activities which formed new surface and sub-surface glacier lakes at ablation zone [*Bajracharya et al., 2007*].

Glacial lake and Glacial lake outburst flood (GLOF)

A glacial lake is a large reservoir of water in, on or near the glacier created by glacial processes as glaciers melts at frontal zone, it creates the empty space which is filled by melt water which eventually become a lake due to gradual accumulation of water. They may be either ice dammed, or moraine dammed. Glacial lakes can be found almost all over the world with glaciated regions. Most theories reveal that glacial lakes began to form with glacier retreat all over the world near the end of last glacial period. Most of the glacial lakes in HKH region are the result of glacier ice and snow melting and deposition of unstable lateral moraines due to increasing temperatures that lead to more glacial lakes in times to come [*Rasul et al., 2011*].

Glacial Lake Outburst Flood (GLOF) is a sudden release of huge amount of debris mix water from the glacial lake flows downstream [*ICIMOD, 2011*]. The GLOF process is supported by the wreckage of glacier ice, the breakdown of moraines due to erosion and gradual leakage of water reduces the strength of lake to contain water, therefore the pressure exerts by the water force lead to the outburst and form a debris flow or flash flood. The intensity of possible flood depends on the speed of outflowing water or the discharge rate and the volume of the water which is usually high in cases of GLOF's, so the higher the volume and discharge rate, maximum would be the severity of flood downstream [*Worni et al., 2012*].

Glacial lake mapping and GLOF modelling using RS and GIS

There are number of approaches to assess various parameters to understand the nature of glacial lake during field surveys which may include observations by visual records, photography, understand local geology, physical settings of the site, physiography of the lake outlet, lake dimensions and stability of moraines and its composition. Bathymetric data is another critical parameter to consider for GLOF as lake depth is used to estimate the volume of the water released in case of GLOF which can be collected by using advance technology and Boat and Sounder method [*Khanal et al., 2015*].

In general, most of the glacial lakes are found at high altitudes due to which it is difficult to reach physically for detailed assessments, investigations, mapping and monitoring [*Anand, 2014*]. It also needs extensive time, resources in terms of human and financials therefore, the remote sensing data and GIS techniques provide great help. Freely available satellite imagery of Landsat and Sentinel are used to monitor the temporal change of glacial lakes. The normalise water index (NDWI) and modified normalise water index (MNDWI) are frequently used indices to extract lake using satellite data [*Huggel et al., 2004*].

The Geographical Information System (GIS) and remote sensing (RS) tools and techniques supports the detailed study, analysis and monitoring of various features of glaciers and glacier lakes as most of the glacier lakes are located at high altitudes that are difficult to assess physically. The assessments of some critical characteristics of glaciers like snow line, moraine type, lake area etc can be easily identify on remote data i.e. satellite images. The remote sensing data of high spatial resolution i.e. Digital Terrain Model (DEM) and freely available software's i.e. HEC-RAS and HEC-GeoRAS can be used to model the possible GLOF and identification of low-lying at-risk features. The results of the remote sensing data coupled with ground truthing can be best approach for GLOF mapping and modelling [*Banerjee, 2003*].

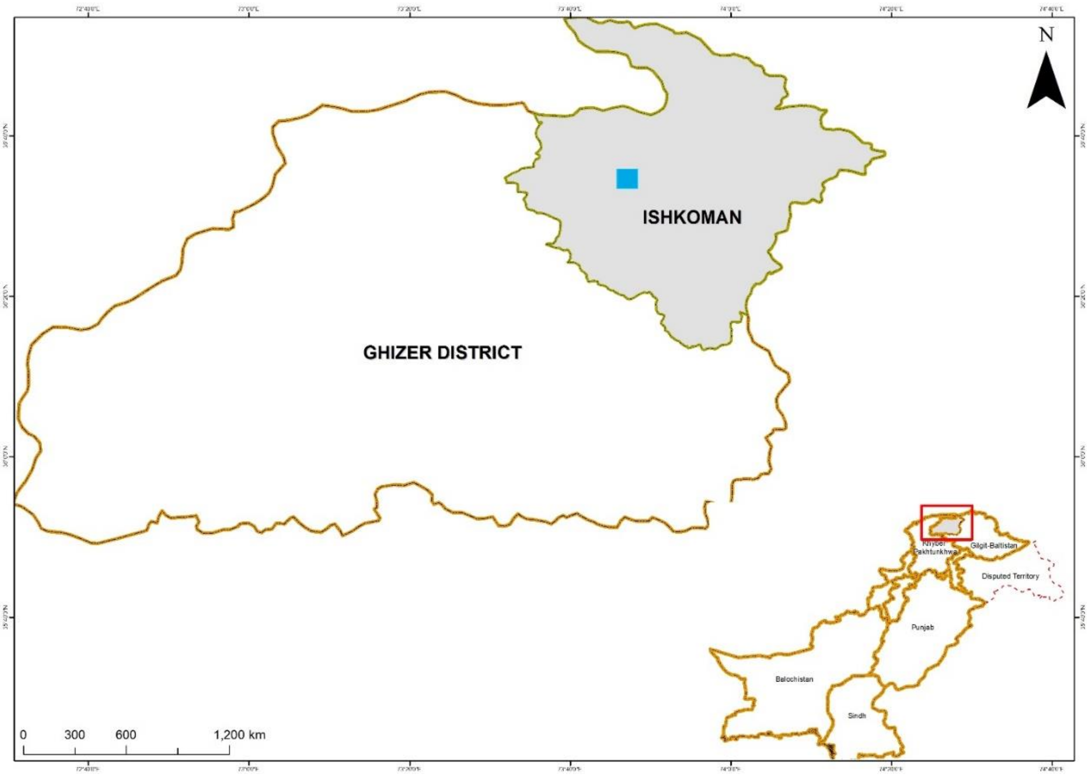


Fig. 1. Map of study area showing location of Deran Lake

The study is focused on the mapping and modelling of glacier lake outburst flood from Deran glacier in Ishkoman valley in high mountain region of Gilgit Baltistan. Deran glacial lake is in NE of Gutulti watershed at elevation of 3436m a.s.l in Tehsil Ishkoman District Ghizer. The site is located at a ground distance of 148 km away from Gilgit city. Deran glacial lake is accessible by foot from Gutulti village. The coordinate of study is lat. 36.593767°N and long. 73.811659°E.

Brief review of the problem

Gilgit-Baltistan is in the lap of the world's highest mountain ranges, namely Karakorum, Himalayas and Hindukush, having more than 5000 of glaciers and hazardous glacial lakes [*ICIMOD, 2005*]. Deran glacial lake is developed at the terminus of Deran Glacier, located in the Gutulti watershed Ishkoman valley in Hindukush mountain ranges in north of Pakistan. Deran Glacier generated outburst floods in 2003 triggered by high melting of glacier with increase the volume of glacial lake and caused huge erosive damage to forest land, agricultural land, link roads, suspension bridges and water channel along the mainstream. Deran watershed having four glaciers and three glacial lakes. Out of three, Deran glacial lake is one of the potential lake due to temporal increase of size and volume of water.

Deran Nala hosting four parallel glaciers. Gradient of eastern glacier is relatively high, and it looks like hanging position. This glacier is highly deformed without any debris covers material. The glacier tongue is thinning, and glacier ice mass is moving upward. Potential could not be physically assessed because of inaccessibility. On southern side along the right lateral moraine a medium sized glacial lake exists. This lake has been developed by push moraine of hanging glacial tributary moving from northward and the lateral moraine of another glacier from its western side. The melt water at supra and en-glacial conduits pour down into the lake and discharges from it in less amount. The lake is bounded by stable moraines and low probability of its outburst, because both adjacent glaciers are retreating phase. Central glacier is located between the two glaciers. The snout of glacier is covered by debris materials and is susceptible for partially blockage of the glacier run off due to avalanches hazard which are triggering from the northern avalanche run out zone. Small pounds observed along their lateral moraine.

Downstream valley is narrow and highly exposed to GLOF, all infrastructures which are located along the banks of the main perennial stream are under the great threat of this hazard. Any potential GLOF/flash floods from the glacier can reach down the villages and may cause heavy damages along the valley banks. Based on the situation, it was necessary to assess the situation in detail to understand the expected damages to downstream and prepare mitigation accordingly.

This study aims to 1) analyze temporal changes in the glacial lake using time series (1991-2015) remote sensing data; 2) to develop Glacier Lake Outburst Flood (GLOF) scenarios and to identify downstream inundation zones. The research also explains that the formation of the moraine glacial lakes is the complex natural process which can modify the downstream land topography and flood plain environment and pose a potential of financial losses. Therefore, it's very important to understand the whole mechanism of lake development, variations and changes occurred due to climatic and anthropogenic activities, elements that may initiate an outburst, route of the outflowing flood water. A model has the capability to predict all those parameters to find approximate time and situations of GLOF onset to ensure the downstream settlements are prepared enough to handle any disastrous conditions.

Method and data

The study is focused on the future possibilities of GLOFs from Deran glacier lake. The process was carried out by conducting couple of extensive ground surveys during 2015 for the collection of data needed for glacier lake mapping and GLOF modelling. The surveys included the profiling of cross section of river, assessment of flood plain, historical flood zones, flood safety structures, participatory risk assessment with community by interviews and group discussions.

Remote sensing data from Landsat satellite for the year 1991, 1996, 2001, 2009 and 2015 were acquired from USGS website for free of cost, for the identification and temporal delineation of water bodies (Glacial Lakes) and mapping of land cover changes and the Digital Terrain Model (DTM) of Shuttle Radar Topography Mission (SRTM) with 10m resolution was clipped to area of interest and used in flood modeling to calculate glacial lake volume to develop GLOF simulation to anticipate downstream risk.

Field data collection for river profiling

River cross section data was collected using GPS and Range finder, due to unavailability and remoteness of the study area to carry heavy machinery like Total Station, manual and simplified approach was used for river profiling. Water discharge was calculated using "Float Method", the steps of discharge calculation was repeated thrice for each flow to ensure accuracy. The standard equation (eq.1) was used for discharge calculation.

$$Q = V \times A \tag{1}$$

where Q - discharge, V - velocity, A - width×depth.

Delineation of glacial lake

Remote sensing and GIS are the most used technologies of current age that have been proven to have capabilities to assess and investigate water bodies and to monitor changes in glaciers and glacial lakes. The free access and availability of satellite images/data for a large geographical area for different time/years that helps to monitor the changes to understand the phenomenon and easy interpretation of data are the common reasons of widespread use of RS technology. In this study, Landsat images were selected to assess the lake dynamics and monitor the spatial and temporal changes to investigate the situation due to availability of reasonable spatial resolution of 30m. Three snow and cloud free scenes of Landsat-5 Thematic Mapper (TM) for year 1991, 1996 and 2010, two scenes of Landsat-7 Enhanced Thematic Mapper Plus (ETM+) for year 2000, 2005 and one scene of Landsat-8 Operational Land Imager (OLI) for year 2015 from the month of August were acquired from USGS website [*https://earthexplorer.usgs.gov*]. The field work was conducted in summer season to collect data as lake has its maximum volume due to high melting and rains and higher discharge rate. The chances of lake outburst and overflow increases in summer due to greater volume and erosion of moraines.

In this study, Normalized Difference Water Index (eq.2) proposed by McFeeters in 1996 was used for delineation of glacial lake. Modified Normalized Water Index (MNDWI) was also used to validate the NDWI results. These indices indicate the presence of water, NDWI values ranges between -1 to +1. Most of the water features are found closed to +1 value. McFeeters set "zero" as the threshold value for water bodies. The values towards -1 indicate the vegetation and bare soil or land features [*McFeeters, 1996*].

The equation used for NDWI calculation is:

$$\text{NDWI} = (\text{GREEN-NIR}) / (\text{GREEN+NIR}). \tag{2}$$

It was noticed that the McFeeters index was unable to distinguish water feature from built-up as at some locations where water body and soil co-exists; the reflectance values are mixed up and difficult to differentiate the actual area of water body. To solve such accuracy issue and to ensure satisfactory results, a Modified Normalized Water Index (MNDWI) was proposed by Xu in 2006, in which NIR band was replaced with SWIR band. MNDWI can depress the built-up and other background features information effectively while express water feature information and make it possible to accurately extract water body information from the target area due to higher reflectance in Green and MIR bands. The threshold value for MNDWI was set to Zero like NDWI but the manual editing brought more refinement and accuracy in delineation of water bodies [*Aggarwal et al., 2013*].

The equation for MNDWI calculation is as under:

$$\text{MNDWI} = (\text{GREEN-MIR}) / (\text{GREEN+MIR}). \tag{3}$$

Extensive manual editing and delineation of lake was carried out using Google Earth images and adjusted with reference data i.e. photographs and ground observations for mapping the final lake.

Lake depth and volume

The depth of the lake is generally measured using highly sophisticated methods and tools or by applying commonly used "Boat and Sounder" method, but due to unavailability of Boat and other equipment's, Weighted Cord Method was used with GPS device, the Inverse Distance Weighted Interpolation (IDW) was choose based on the literature, as for many aquatic studies IDW was applied due to its exactness which gives the depth values for the unknown points based on the distance of surrounding known points. The surveyed GPS points were converted into lake boundary and attribute was generated with elevation information, the Triangular Irregular Network (TIN) created and volume of the lake and area was calculated using surface volume tool in 3-D Analyst toolbar of ArcGIS. The results were copied in MS excel for further analysis and generate graphs.

Land cover mapping

Temporal land cover of Gutulti watershed was mapped using unsupervised classification on Landsat images of 1991 and 2015 in ArcGIS interface. The area of each class was calculated using Field Calculator in Spatial Analysis tool and graphs were develop in MS Excel.

GLOF Inundation Mapping

Flood inundation zones in case of GLOF were generated in HEC-RASS Software using unsteady flow method based on the river profile and bathymetric data and high resolution DTM surface and GLOF risk maps were created in ArcGIS environment.

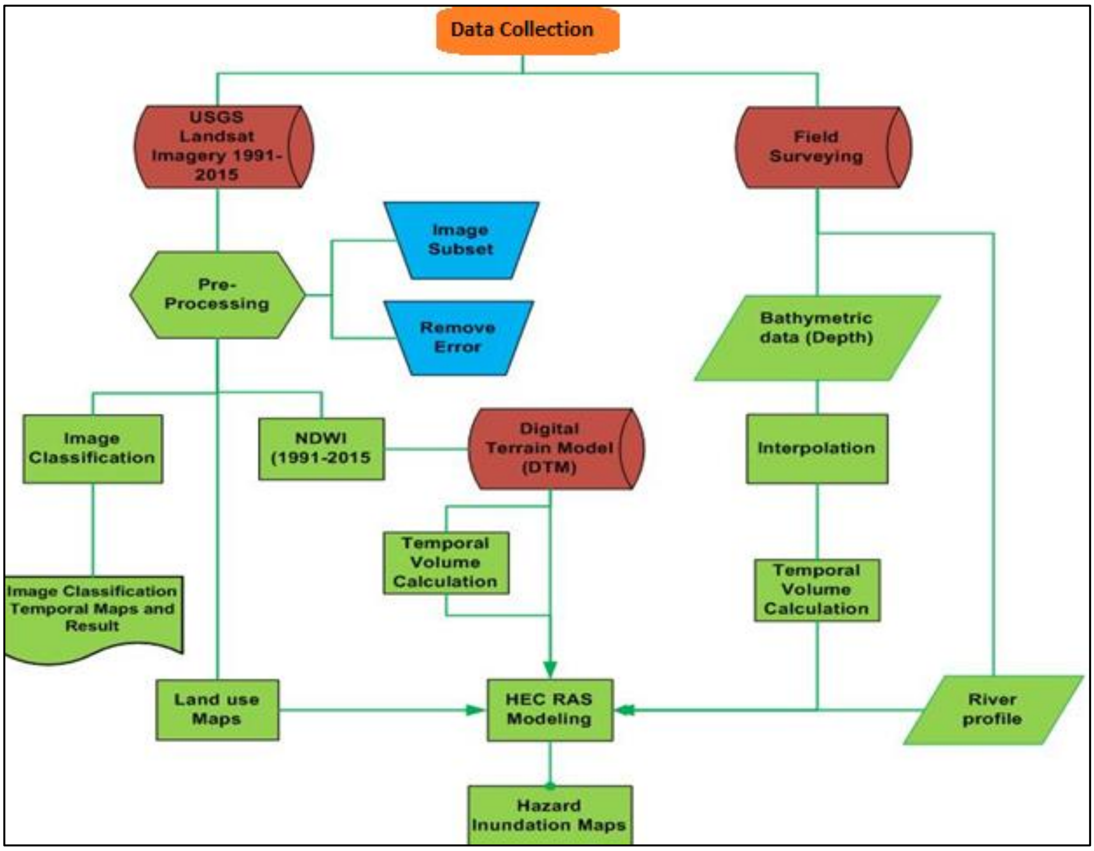


Fig. 2. Flow chart of the methodology for the mapping and modelling of GLOF

Analysis

The assessment and field surveying coupled with remote sensing method revealed that the Deran lake was increased in size and depth due to high melting and degradation of forest cover and rangeland that increased the chances of GLOF events and ultimately flooding in low lying areas.

In general, both natural forces and human actions convert these natural processes into disasters. Natural forces like increase of temperature and change in precipitation pattern coupled with human activities like high livestock density, free grazing, over exploitation of forest products (especially for fodder and fuel wood) conventional farming, forest depletion and weak relationships result changes in localized climate and its impacts.

In 1991, Deran Lake has an area of 7987.34 sq.m which was taken as baseline for further comparison. This was increased up to 11633.68 approximately 15% change in area in 1996, which further increased to 14806.82 (approx. 19%) in 2001. In 2009, it goes up to 19300.65 (24 %) and in 2015 it reached to 24337.22 which is 31% increase in lake area. The statistics shows the gradual increase in size of Deran lake over the study timeline.

Table 2. Temporal change in Deran Lake area between 1991 and 2015

Year	Area (Sq.m)	% Change
1991	7987.34	-
1996	11633.68	14.90
2001	14806.82	18.97
2009	19300.65	24.72
2015	24337.22	31.18

The temporal change in lake area between 1991 to 2015 can be observed in below images.

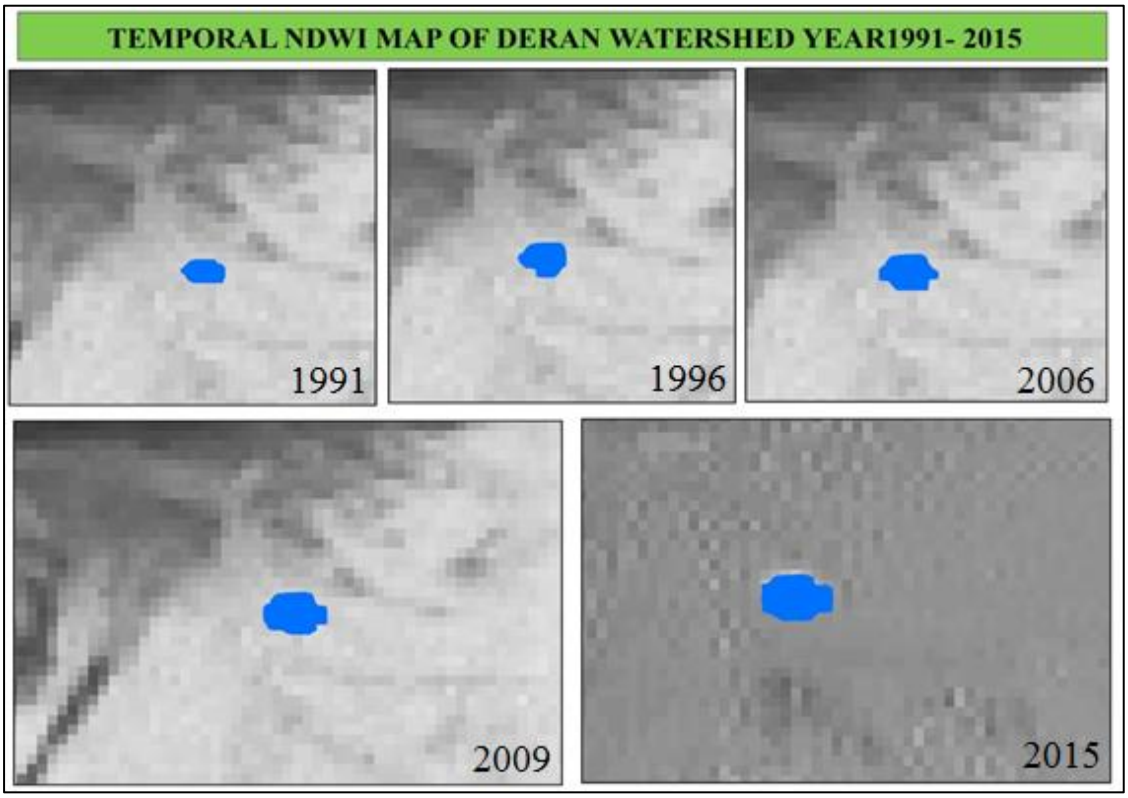


Fig. 3. Map shows the gradual development of Deran Lake from 1991-2015

The NDWI results were supported by the findings of the interviews and discussions conducted during field surveys about historical records that the ablation area of the glacier has witnessed a severe melting in last few years that weaken the glacier ice sheet and gradual melting lead to the formation of small water ponds and later on the combination of all small ponds converted into a huge lake with massive volume and bigger in size.

Deran glacial lake shows the visible change in area (Fig. 4) that indicates the climate change impact on this part of the world. The threat of GLOF hazard to downstream community is also increase with respect to temporal enlargement in lake size.

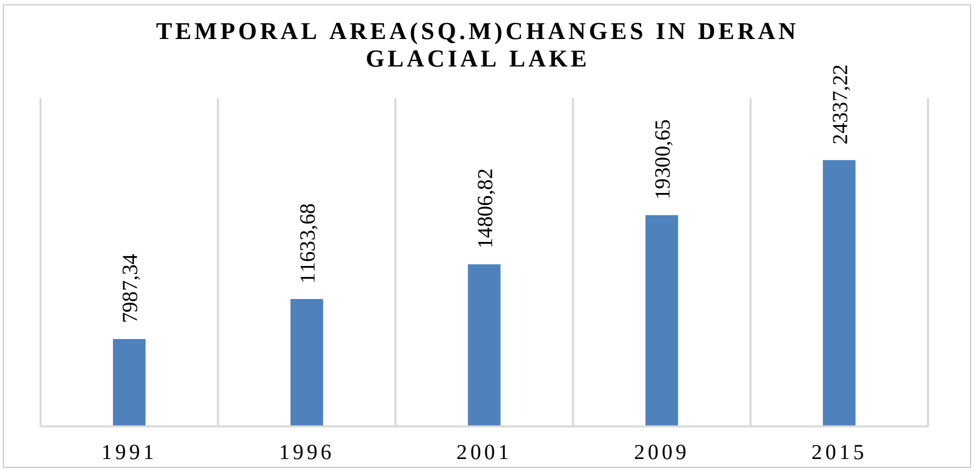


Fig. 4. Temporal change in lake area during 1991 to 2015

The GPS points containing the latitude, longitude and depth values were interpolated in ArcGIS environment using Inverse Distance Weighted Interpolation (IDW). The polygon of a shoreline boundary of the Lake was created using survey points and populated the attribute with elevation information (i.e. Z Values). The Lake boundary or shoreline depth was taken as “Zero”. The output surface resulted from the interpolation was converted into Integer and created a surface of Triangular Irregular Network (TIN). A volume of the Lake and area was calculated using surface volume tool in 3-D Analyst toolbar of ArcGIS. In 1990, the volume was 98695.8 m^3, while it increases to 128202.5 m^3 in 1996. In 2001, it was further increased to 145040.4 m^3 and reached at 159021.9 cubic meter in 2009 and 163852.6 m^3 in 2015 respectively as shown in (Fig. 5).

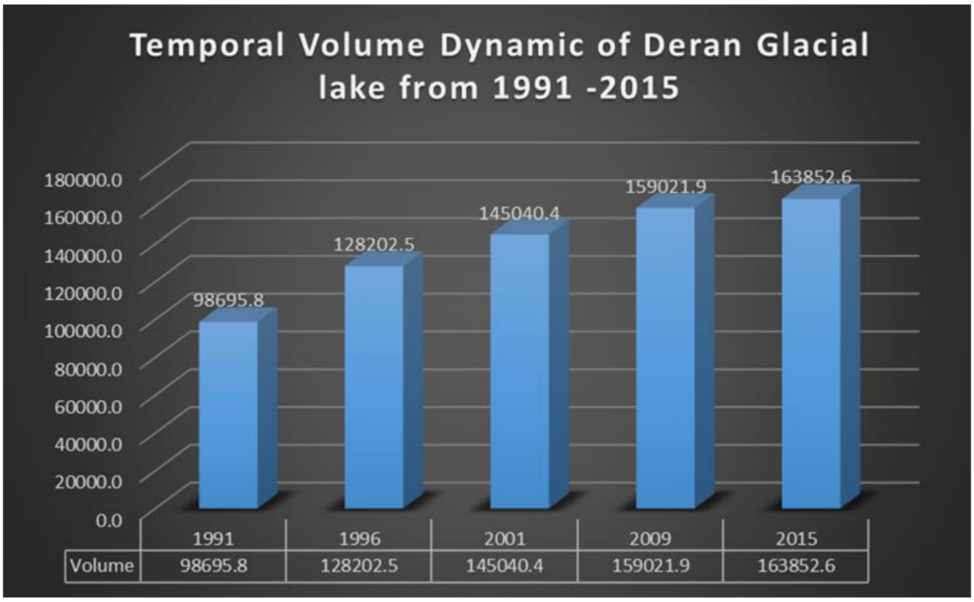


Fig. 5. Temporal change in volume in Deran Lake

The distribution of different land cover and their percentage in 1991 is presented in (Fig. 6). Major percentage of the watershed is covered by Glacier and snow cover (40.62 %), rangeland (36.06 %), with barren land (22.43%), Forest/Vegetation (0.88 %) and water bodies (0.01 %). The area covered by glacier and snow cover is 100.0043, rangeland 88.7817, barren land 55.2159, forest and vegetation 2.162 and water bodies 0.0141 sq.km respectively.

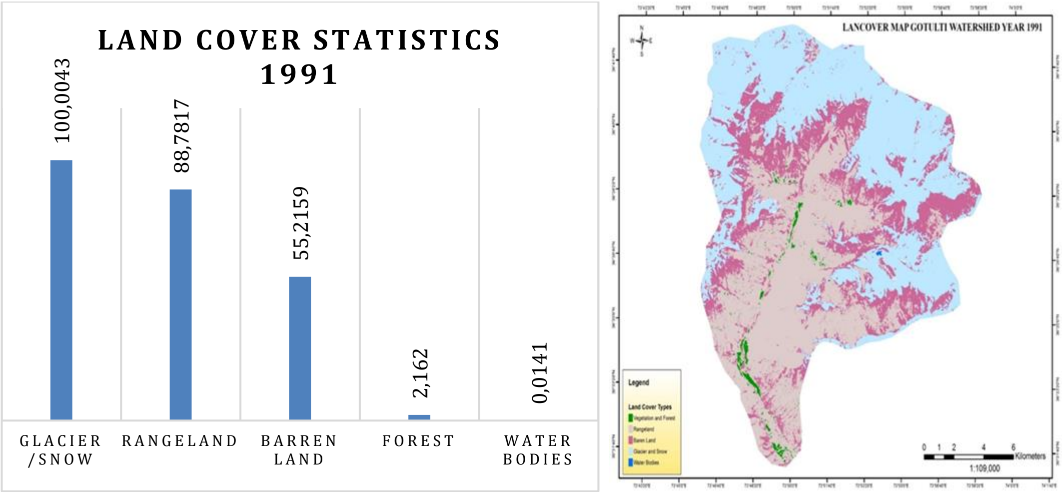


Fig. 6. Land use and land cover statistics in 1991 in Gutulti Watershed

The distribution of different land cover in 2015 is presented in the (Fig. 7), where it shows major percentage of the watershed is covered by barren land (52.82%), rangeland (23.36%), Glacier and snow cover (21.19%), Forest/Vegetation (1.91%) and water bodies (0.01%). The area covered by barren land is 130.49, rangeland 57.70, glacier and snow cover are 54.12, forest and vegetation 47.1and water bodies 0.02 sq.km respectively.

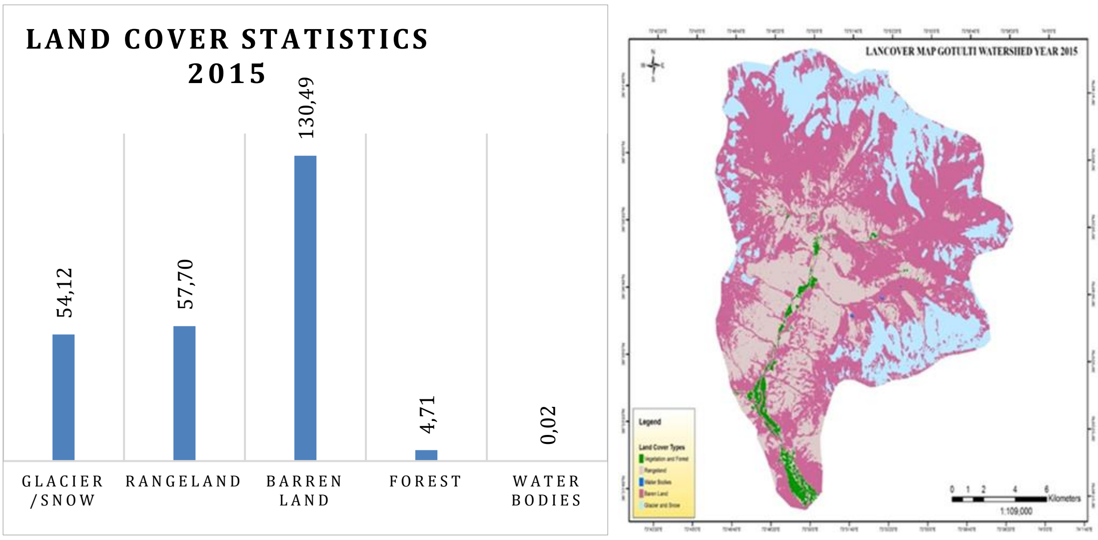


Fig. 7. Land use and land cover statistics in 2015 in Gutulti Watershed

GLOF map was generated using unsteady flow method in HEC-RAS software using lake volume, river profile and DTM data. Map (Fig. 8) shows two scenarios of flood zones if it triggers. 1st scenario is based on release of 56000 m³ water from glacial lake with data time interval of 10 minutes. The GLOF exposures statistic are 384.17 acres of forest and vegetation, two houses, one bridge and Stockpile in Faizabad Ishkoman, Govt School, a community centre and a transformer in Ishkoman Payeen and eight houses, one bridge and one transformer in Tushkin village.

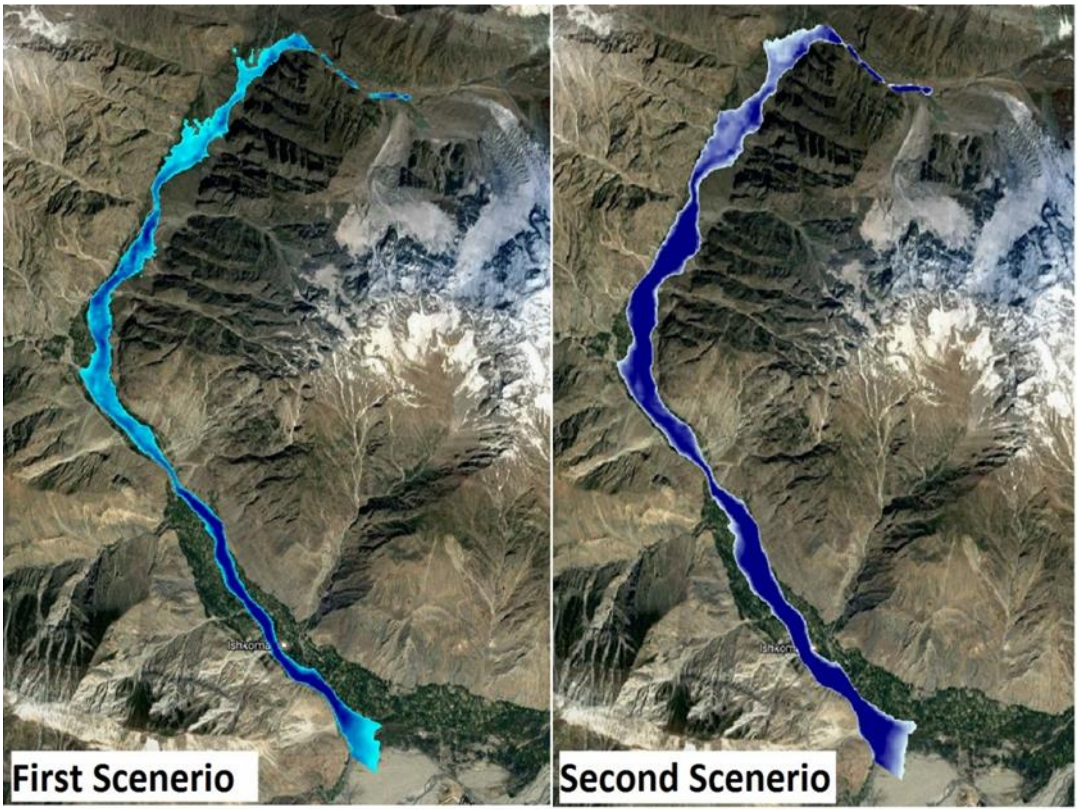


Fig. 8. Map shows the expected flood extents downstream in Gutulti valley

The second GLOF scenario is based on release of 56000 m³ water from the lake with time interval of 10 minutes. The GLOF exposures statistic are 438.39 acres of forest and vegetation, four houses one bridge, depot, a community centre and Stockpile in Faizabad Ishkoman, AKES School, Govt school, community centre, Flour Mill, two bridges, Timber factory and transformer in Ishkoman Payeen and twenty four houses, one Mosque, one Private School, two shops and a transformer in Tushkin village.

The GLOF risk maps (Fig. 9) were developed by integration of GLOF inundation zone with infrastructure data collected during ground surveys.

Conclusions

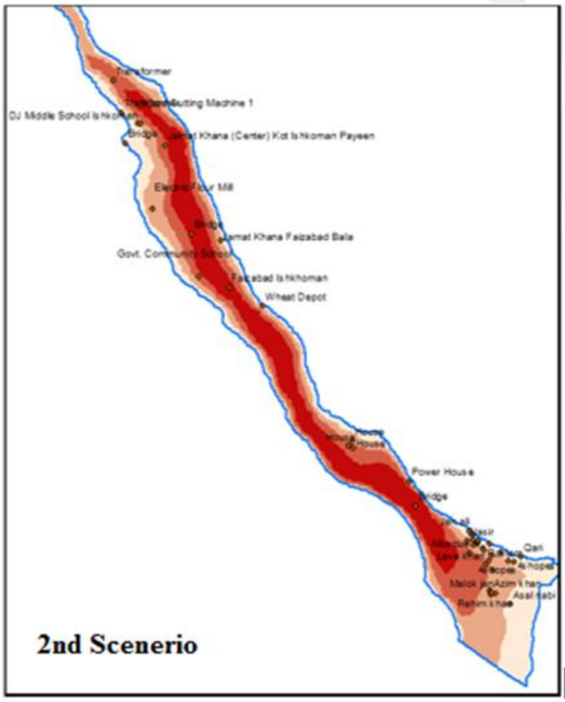
The assessment of a glacier lake outburst flood risk in a step wise systematic method including field surveys and community discussions coupled with desk study using remote sensing resulted in a comprehensive picture of the hazard exposure and the susceptibility of downstream vulnerable communities. The findings can be a good base for the policy makers and planners to adopt feasible interventions and safety measures or mitigation. The present study applied the methodology of lake outburst and simulate the flood scenarios to model the expected GLOF's and foresee the anticipated risk. The study shows a significant impact on critical infrastructures and lifelines of downstream communities. The real time losses can be high if indirect damages are considered, as the intensity and magnitude of GLOF can vary. Therefore, a comprehensive data especially the geotechnical parameters for moraine glacier lake can significantly enhance the findings.

Based on the analysis of the data collected during the study revealed that the Glaciers in Deran nallah is in retreating phase as the indication of end moraine along the valley witnesses. The total catchment and ablation zone of the glacier is 22.6 Sq. Km and its Snow Equilibrium line limit is 4070 m a.s.l. The gradient of the glacier varies in different parts. The snout is very steep, in the middle portion it is gentle, and the accumulation zone is very steep. The lake has been developed by push moraine of hanging glacial tributary moving from northward and the lateral moraine of another glacier from its western side. The lake extent has been increased to

31.18 % since 1991 to 2015 due to high temperatures and added the water volume up to 60%. As a result of high melting, the ice and glacier cover has been receded from 42.62% to 21.91% in study timelines i.e. 1991 to 2015. The findings help us to recommend that a thorough investigation of the carrying capacity of lake should be carried out and a plan for at risk communities downstream should be in place to avoid future losses.

Elementt At Risk GlOF

akdn_id	az_n_en	Name_Inf
504806	Tushkin	House
504806	Tushkin	House
504806	Tushkin	House
504806	Tushkin	House
504806	Tushkin	House
504806	Tushkin	House
504806	Tushkin	House
504806	Tushkin	Transformer
504806	Tushkin	House
504806	Tushkin	Mosque
504826	Faizabad Ishkhoman	Bridge
504826	Faizabad Ishkhoman	House
504826	Faizabad Ishkhoman	House
504826	Faizabad Ishkhoman	Stockpile
500652	Ishkoman Payeen	Govt. School
500652	Ishkoman Payeen	Bridge
500652	Ishkoman Payeen	Jamatkhana
500652	Ishkoman Payeen	Transformer



Elementt At Risk GlOF

Village	Infra_Name	Total
Faizabad Ishkoman Payeen and Tushkin	AKES School	1
	Bridge	3
	Depot	1
	Flour Mill	1
	Govt. School	1
	House	28
	Jamatkhana	2
	Mosque	1
	Private School	1
	Shop/Market	2
	Stockpile	1
	Timber Factory	1
	Transformer	3

Fig. 9. GLOF risk map shows downstream infrastructure at risk

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