GLACIAL LAKE OUTBURST FLOODS (GLOFs): A CASE STUDY OF GEEPANG GATH GLACIAL LAKE, LAHAUL & SPITI AND CHAMBA DISTRICTS, HIMACHAL PRADESH

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Abstract	**With the projected increase in the frequency and intensity of extreme events including floods, droughts, landslides etc which are attributable to climate change, disaster management need greater attention. Susceptibility of the State of Himachal Pradesh to the vagaries of climate change has now been well documented. Scientific insight gained from the analysis of multi spectral Satellite images carried out by the authors suggests that spatial extent of majority of glaciers is changing very fast leading to the formation of moraine dammed lakes. Formation of such lakes is posing potential threat to the infrastructure and human life thriving in the downstream areas of many drainage systems originating from the snow clad mountains ranges of the State. Various studies have been carried out on this vital issue of climate change and reveals that there is an alarming increase in such potential lakes which can be disastrous in the event of any break due to one or the other reasons. The present study has been carried out using LISS III satellite data. Geepang Gath glacier lake is a pro glacial or the moraine dammed glacial lake as it has been formed at the front of the snout of the glacier which showed an increasing trend in consonance with the receding of the Geepang Gath glacier. In order to make an assessment of the damage likely to be occurred in case this lake bursts, mapping for the various geomorphic units was carried out along the corridor classifying in 3 buffer Zones at 100 meter interval along the river course on both sides from top to bottom. These three zones have been studied in great details along the segment in which the study area has been divided by virtue of its coverage. Each zone and each segment signifies the likely impact on its land use land cover by virtue of the heavy discharge in the river course in case the lake burst. The volume and discharge estimation has also been calculated using empirical relation based on the average depth calculated from bathymetric studies of the lake as carried out by NCOR. The present study has made it possible to make an attempt to visualize the impact of flood water in case of bursting the Geepang Gath glacial lake and its damage on different landforms unit along the river course.**
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Glacial lake outburst floods (GLOFs): A case Study of Geepang Gath Glacial Lake, Lahaul & Spiti and Chamba District, Himachal Pradesh

1. Introduction

1.1 Glaciations in the Himalaya:

During its geological history, the earth has experienced alternate cycles of warm and cold climates. During cold climate, glaciers and ice sheets have formed on the surface of the earth. Geological evidence suggests that the earth has experienced glaciations during, Perm-Carboniferous and in the Pleistocene period (Embleton and King, 1975). Precambrian tillites and boulder-beds are reported from many parts of the world, such as Scotland, U.S.A. Clear evidence of Carboniferous-Carboniferous ice age is also established in India and South Africa. The Carboniferous-Carboniferous glaciation was followed by Mesozoic era, during which the world temperature was higher than that of today and no evidence of glaciation was observed in the geological formations of that period. In Cenozoic era, large-scale glaciation was experienced, which includes glaciation during Pleistocene and Quaternary periods (Smith *et al.*, 2005). It has also influenced the present distribution of glaciers on the earth's surface. During Pleistocene the earth's surface had experienced repeated glaciation over a large land mass. During the peak of glaciation, the area covered by the glaciers was 46 Million sq. km. (Embleton and King, 1975). This was more than three times the present ice cover of the earth. Available data indicates that during the Pleistocene, the earth has experienced four or five glaciation periods separated by an interglacial periods. During an interglacial period, climate was warmer and deglaciation occurred on a large scale. The most recent glaciation reached its maximum advance about 20,000 years ago when the Himalayan snow line was depressed from 600 to 1000 meters lower than the present elevation due to fall of temperatures by 5 to 8ºC. At present total glaciated area on the earth is about 14.9 million sq. km. Out of this 2.5 million sq km is located in Arctic and 1.7 million sq km in the Greenland ice sheet (Flint, 1971). The remaining 0.7 million sq km area is distributed in the other parts of the World. Himalaya has one of the largest concentrations of glaciers outside the Polar Regions and some estimates suggest that the number could be as high as five thousand (Kulkarni and Bahuguna, 2001).

In the Himalaya, glaciers cover approximately 33000 sq. km area, and this is one of the largest concentrations of glacier-stored water outside the Polar Regions. Melt water from these glaciers forms an important source into run-off of North Indian Rivers during critical summer months. This makes these rivers perennial and has helped to sustain and flourish the Indian civilization along the banks of Ganga and Indus. This supply is available during dry periods and naturally regulates the flow of large rivers thus compensating extremes of precipitation. Glacial activity also generates sediments. However there have been several evidences in recent geological history about the glacier mass fluctuations resulting in the stream runoff originating from them. Stream runoff is an important component in planning of water resources and micro and mini hydroelectric projects. Glacier mass fluctuations are also indicators of global climatic changes. In the context of the Himalayan glaciers, which are source of many giant north Indian rivers, systematic monitoring of Himalayan glaciers is of paramount importance in view of their large number and area covered.

Global warming has already caused a significant glacier ice loss since the Little Ice Age (AD 1550-1850) (Denton and Hughes, 1981) resulting in both glacier retreat and thinning (loss of ice volume). Many glaciers in the Himalayan mountain chain are reported to be gradually retreating (Mayeswki and Jeschke, 1979; Li *et al.*, 1998; Kulkarni and Bahuguna, 2002; Raina, 2004; Kulkarni and Alex, 2003; Kulkarni *et al.*, 2005; Kulkarni *et al.*, 2006). Catastrophic natural processes triggered by these glacier changes were responsible for considerable death and destruction throughout the mountains. These processes included ice avalanches, landslides and debris flows, outbursts from moraine-dammed lakes and also outbursts from glacier dammed lakes. Glacier avalanches have occurred where glaciers have retreated up steep rock slopes. Sources of debris flows are frequently moraine complexes exposed during glacier retreat, which may be ice-cored. Outbursts from moraine dammed lakes result from the catastrophic breaching of the moraine dam - a process that is commonly initiated by glacier avalanches - generated waves that overtop the moraine. Himalayan and Trans-Himalayan glaciers are in general state of retreat since 1850 AD. Most of the Himalayan glaciers are covered by debris, which slows down their melting.

1.2 The Present Scenario:

It is estimated that the Himalayan glaciers provide around $8.6X10^6$ m^3 of water annually. The three great rivers of India-the Indus, the Ganges, and the Brahamputra collectively provide close to 50% ($320Km^3$) of the total country's utilizable surface water resources ($690Km^3$). Since the mid-1970s the average air temperature measured at 49 stations of the Himalayan region rose by 1° C with high elevation sites warming the most (Hasnain2000). This is twice as fast as the 0.6° average warming for the mid –latitudinal northern hemisphere over the same time period (IPCC 2001b), and illustrates the high sensitivity of mountain regions to climate change (Oerlemanns et.al, 2000).

Monitoring the snout of glaciers using in-situ and remote sensing methods has received the bulk of attention. More than 50 glaciers have been monitored over different time periods. In consonance with the global trend, the majority of glaciers in the Indian Himalaya have been retreating since the recording began around the middle of tne nineteenth century (Raina 2009). Karakoram Himalaya is an exception to this trend (Hewitt, 2005): Fowler and Archer, 2006). There are temporal and spatial variations in the rates of retreat, the rates varying from < 5m/year to about 50m/year (Raina and Srivastava, 2008). The retreat was generally around 5-10m/year till up to late 1950s: the rate of retreat increased during mid-seventies, which continued up to mid-nineties, touching a value of 25-30 m/year in some glaciers. It is contended by some that there is a general slowing down in the rate of retreat in the late nineties and in the decade of 2000(Raina, 2009: Bali et al., 2010). But there is no consensus (Naithani et al, 2001, Bhambri et al, 2011a).

Based on the various studies carried out, it has been found that Himalayan glaciers are in a state of general retreat since 1850 (Mayewski & Jeschke 1979). The Khumbu glacier, a popular climbing route to the summit of Mt. Everest, has retreated over 5 km from where Sir Edmund Hillary and Tenzing Norgay set out to conquer the world's highest mountain in 1953. Gangotri glacier which is one of the best documented glaciers in the Indian Himalaya as far as its snout position demarcation is concerned. The snout of the glacier "Gaumukh" is about 18 KM from the holy shrine of Gangotri. The snout of the glacier has been under the state of continuous recession since 1935 (Auden, 1937). Geological Survey of India (GSI) has monitored the snout of the glacier since 1935 till 1996. The data reveal that the glacier has retreated by 1147m, with an average rate of 19m/year between 1935 and 1996. The total area vacated by the glacier during 1935 to 1996 is estimated to be 5, 78,100 m^2 or $0.58Km^2$ (Srivastava 2004).

Bara Sigri glacier a north westerly facing glacier in the Chandra valley with surface area of about 137 Sq. Km. and 27 Km length is one of the largest glaciers in Himachal Himalaya. Snout of the glacier, at present, is far away from the Chandra River, but in times past, as is revealed by the glacier landforms and the trim line, it must have extended right up to the present river valley. This glacier , as per the available records, had in the year 1793 AD, extended up to the river, and, in fact had blocked the course of the Chandra river (Egerton ,1864).Average retreat and the area vacated by the glacier along snout front, over the last nine decades-1906 to 1995 is 4.33 sq.km. During 1906-1956, the area vacated was the highest till data (3.44sq.km) and during the period 1963-1977 it was at the minimum (0.24sq.km.) and could be attributed to the positive trend in the snow cover variation in the Himalayas that resulted in the positive mass balance recorded by some of the glaciers in the adjacent areas of Himachal Pradesh. The glacier recession once again accelerated during 1977-1995 and likewise could be attributed to the conditions that led to the negative trends in the snow cover variation and the mass balance recorded in adjacent Chhota Sigri glacier by the DST teams and in adjacent parts of Himachal Pradesh by the GSI.

Zemu glacier is the largest glacier in the eastern Himalayas with a total surface area of about 42 km^2 and a linear length of about 20 km. The glacier, as compared to the snout position, as fixed by La Touche, revealed a linear shrinkage of about 414m between 1909 and 1965 (Raina & Bhattacharya 1973). This glacier was under continuous observation of the GSI teams from 1977 to 1986 and is reported to have vacated an area of about 52,443m^2 along the snout front from 1965 onwards. There have, however, been periods -1979-80 and 1984-85, when the glacier snout has been reported to have shown slight advance.

At present the rivers have shown 3-4% surplus water due to a 10% increase in the melting of the glaciers of the western Himalayas, and a 30% increase in the eastern Himalayan glaciers. But, after 40 years, most of these glaciers will be wiped out and then South Asia will have water problems. In March 2002, UK's Department of International Development funded a project called Sagarmatha (Snow and Glacier Aspects of Water Resources Management in the Himalayas) to assess the impact of deglaciation on the seasonal and long term water resources in snow-fed Himalayan rivers. This study was vital for policy-makers and especially those working on interlinking of rivers, as the flows available in rivers are likely to change dramatically over the decades depending on the region. The study which reveals some major facts about the melting mountain majesties and warming glaciers, is an eye-opener.

In Upper Indus, the study sites show initial increases of 14% and 90% in mean flows over the next few decades which will be followed by decreasing flows by 30% and 90% of baseline in the subsequent decades in a 100-year scenario. For Ganges, the response of the river near the glacier in Uttarkashi is different from downstream Allahabad. At Uttarkashi, flows peak at between 20% and 33% baseline within the first few decades and then recede to 50% of baseline after 50 years.

Near the source of the Brahmaputra, there is a general decrease in decadal mean flows for all temperature scenarios as glaciers are few in the area and flows recede as the permanent snow cover reduces with increasing temperature. The catchments in the eastern Himalayas which benefit from high precipitation of the summer monsoon, are more vulnerable to impacts of deglaciation than those in the west where the monsoon is weaker.

In short, the deglaciation in the Himalayas is influenced by various factors, climatic, regional etc. However, the main underlying factor is ever increasing warming on the mountains, chiefly because of excess emission of greenhouse gases and Asian brown cloud. The ongoing ice melting is only the tip of the iceberg that will hit us in the near future. As the Indian economy depends to a great extent on agriculture- a highly climate sensitive sector and the knowledge about potential climate change impacts on agriculture has special significance. Agriculture productivity is sensitive to two broad classes (a) direct effects from change in temperature and (b) indirect effects through changes in soils, distribution and frequency of infestation by pests, insects, diseases or weeds etc. Several studies predict that rice and wheat yield would decline considerably with climatic changes in India. As the mountain areas accounts only 21% of the total geographical area of India, where about 60-70% population largely depends on agriculture, horticulture and animal husbandry related activities for their livelihood. If the present trend of climate change continues, this will have an adverse effect on their lifestyles.

1.3 Hazard vulnerability of the State

Mountain areas are especially vulnerable to natural disasters where development over the years has further accentuated the problem by upsetting the natural balance of various physical processes operating in the mountain eco-system. The increased pressure on the mountain environment has contributed in some measure to environmental problems such as landslides, land subsidence, removal of vegetation and soil erosion. According to one estimate, about 58.36% of the land is subjected to intense soil erosion, majority of which is located in the Himalaya. The State of Himachal Pradesh, which forms part of the Northwestern Himalaya, is environmentally fragile and ecologically vulnerable. Geologically the Himalaya is considered to be the youngest mountain chains in the world and is still in the building phase. Natural hazards are matter of immediate concern to the State of Himachal Pradesh, as every year the State experiences the fury of nature in various forms like earthquakes, landslides, cloud bursts, flash floods, snow avalanches and droughts etc. The fragile ecology of the mountain state coupled with large variations in physio-climatic conditions has rendered it vulnerable to the vagaries of nature. The incidence of cloudbursts in the last few years has baffled both the meteorologist and the common man equally. Notwithstanding, the continuous efforts made by the Government to cope with natural hazards through relief and rehabilitation measures, landslides and snow avalanches continue to inflict widespread harm and damage to human life as well as property. The roads that are the State's lifeline are repeatedly damaged, blocked or washed away by one or other acts of nature. In the circumstances, the Government has to divert the already scarce resources of the state for relief and rehabilitation measures as opposed to long term development.

In the Himalayas, during the retreating phase a large number of lakes are being formed either at the snout of the glacier as a result of damming of the morainic material known as moraine dammed lakes or supra glacial lakes formed in the glacier surface area. A glacial lake is defined as a water mass existing in a sufficient amount and extending with a free surface in, under, beside and/or in front of a glacier and originated by glacier activities and/or retreating processes of a glacier. Most of these lakes are formed by the accumulation of vast amounts of water from the melting of snow and by blockade of end moraines located in the down valleys close to the glaciers. In addition, the lakes can also be formed due to landslides causing artificial blocks in the waterways. The sudden break of a moraine/block may generate the discharge of large volumes of water and debris from these glacial lakes and water bodies causing flash floods namely GLOF. A Glacial Lake Outburst Flood (GLOF), also known as a jökulhlaup in Icelandic (A jökulhlaup is technically a sudden and often catastrophic flood that occurs during a volcanic eruption, but is also used to describe other sorts of glacial flooding), can occur when a lake contained by a glacier or a terminal moraine dam fails. This can happen due to erosion, a buildup of water pressure, an avalanche of rock or heavy snow, an earthquake, or if a large enough portion of a glacier breaks off and massively displaces the waters in a glacial lake at its base. Many countries has a series of monitoring efforts to help prevent death and destruction that are likely to experience due to these events. The importance of this situation has magnified over the past century due to increased population, and the increasing number of glacial lakes that have developed due to glacier retreat. There are a number of GLOF events that have been reported worldwide. There are number of such events that have happened in Nepal Himalayas but no such event has been reported so far from Indian Himalayas. On the basis of earlier studies carried out in Himachal Himalayas in Satluj basin, there are about 38 such lakes in entire Satluj basin out of which 14 falls in Himachal part. Similarly 50 moraine dammed lakes in Chenab basin and 5 supra glacial lakes have been mapped using remote sensing. The state of Himachal Pradesh invariably experience flash floods, the cause of which is unknown. In the year 2000, the Satluj valley experiences the heaviest floods causing loss of more than 800 crores. It is still a matter of investigation weather the floods were caused by cloud bursting or due to Glacier Lake Outburst Floods (GLOF) phenomena. The formation of landslide dammed lakes in high altitude zones such as Paraechu in the upper catchment of Spiti basin in Tibet caused tremendous threat to the life and property located in the downstream areas. It is therefore necessary that a constant and repeated monitoring of the upper catchment areas having international dimensions required to be carried out on a regular basis.

2. Study Area:

This lake has known by various names. Some call it Ghepan Gath, Geologial Survey of India (GSI) people call it Gepang Gath, Gaddis' call it Ghepan Ka Alyas'.Ghepan is the most revered deity of Lahaul Valley that's why he is called Raja Ghepan, the King. A peak by the same name rises above the Sissu village that stands tall like an Emperor. A solitary tower keeping a constant vigil. A massive rock face guarding the valley of Lahaul. A turquoise gem specked with tiny icebergs, hidden away in an unknown valley, encased by barren rocky snow clad mountains. Enchanting its rare visitors by its pristine looks. Being born of a receding glacier at one end and giving birth to a roaring stream on another. By standing at its shores, one can witness nature at work and impact of climate change. The area of this lake had increased from 27 ha in 1976 to 98.68 ha in 2019. The area which has been investigated comprise of mainly the catchment along the Sissu Nala and the further downstream along the Chenab River by taking an immediate corridor along the valley further downstream up to the district Chamba.

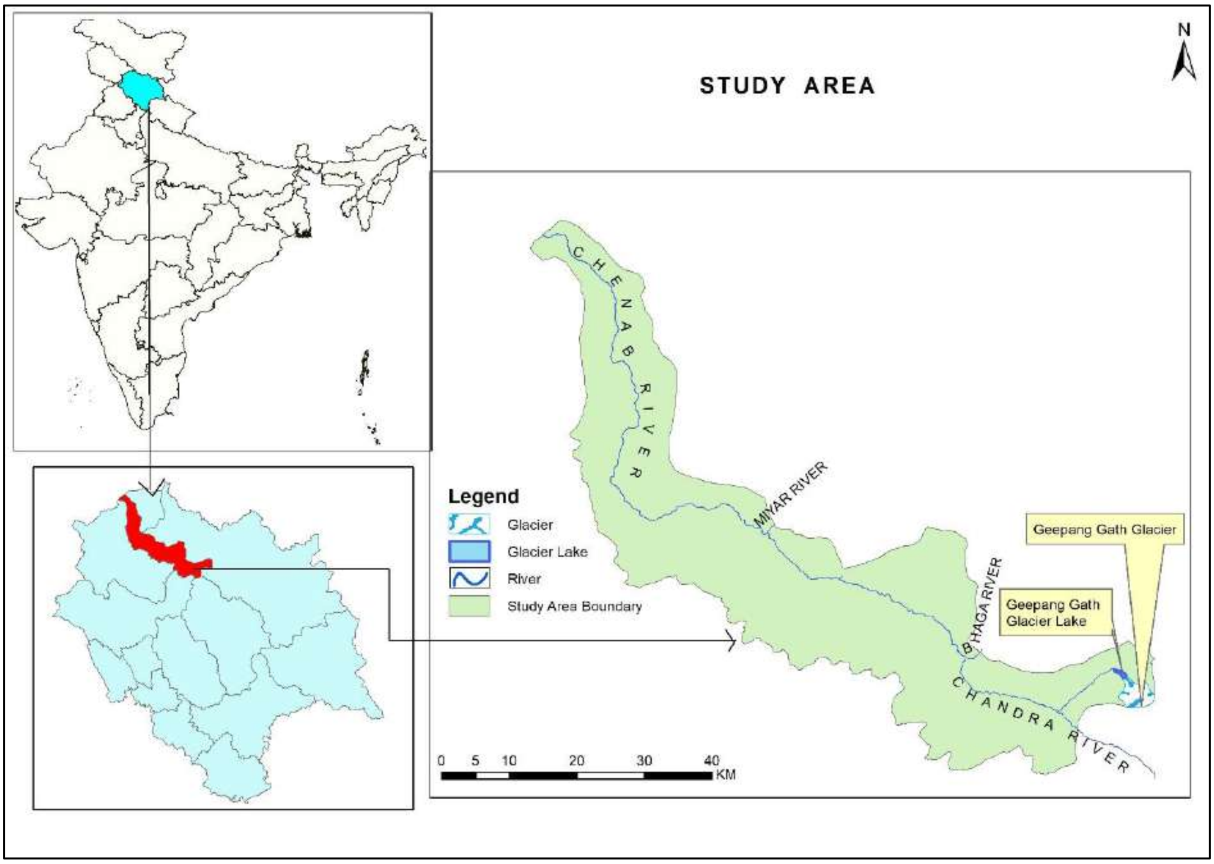

Fig. 1: Location Map of the Study Area.

3. Data Used:

In order to undertake the investigation the following sets of data has been used.

1. Satellite Data Product
   a. LISS III (path/ row : 95/48, dated on 19/10/17 and path/ row: 94/47, dated on 07/11/17)
   b. SRTM 30 meter Digital Elevation Model (DEM)

4. Elevation and Drainage:

The contour map was generated using ARC GIS from SRTM DEM. The contours are spaced at 30 meter vertical interval denoted by their respective elevations in the map. Based on the contour map, it is found that the region by and large is characterized by densely spaced contours reflecting high relief of the area.

The study area mainly comprises of Chenab River as the major drainage system of the catchment. Sissu Nala originating from Geepang Gath Lake situated at an elevation of 4140 Meters above mean sea level joins Chandra River near Sissu village on its right bank. The other major tributaries draining into the catchment are Chandra, Bhaga and Miyar Rivers. Drainage pattern developed is mainly dendritic to sub dendritic in nature as per the satellite image (Fig.2) with the right bank reflecting more of dendritic pattern than the left bank which is characterized mainly be the sub dendritic in nature and the drainage density on the right bank is comparatively higher than the left bank .

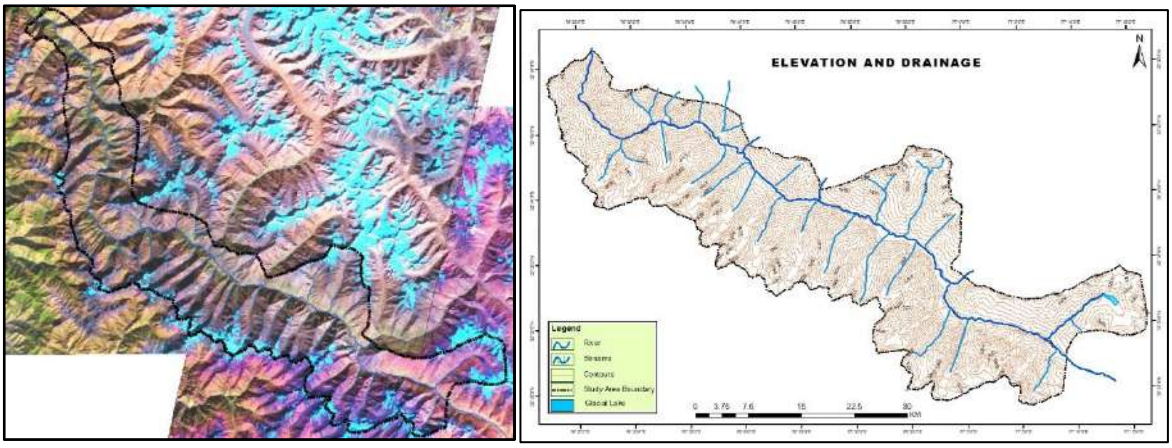

Fig. 2: Elevation and Drainage Map

5. Land Use Land Cover (LULC) of the downstream of Geepang Gath glacial lake:

The land use land cover map of the study area has been prepared using IRS-R2-LISS III –Oct and Nov 2017 satellite data. Based on the satellite data analysis, the dominating land cover units observed in the immediate study area are grass land/pasture land constituting about 819.17 Km^2 i.e. about 44.42% of the study area and wasteland comprises of 537.22 Km^2 of the total area i.e. about 29.12% of the total area. Besides this, Snow cover comprising of 238.96 Km^2 i.e. about 12% of the total area constitutes the third major land cover in the catchment and the forest constituting about 7.9% of the total area (145.84 Km^2) is available in the study area. Agriculture constitutes 4.23% of the study area. The habited area constitutes only about 0.08% of the total area in the catchment (Fig. 3 and Fig. 4). By virtue of climatic conditions, the lower elevations are suitable for the production of cereal crops, stone and citrus fruits and the higher elevations, are most suitable for the growing of seed potatoes, vegetables and temperate fruits.

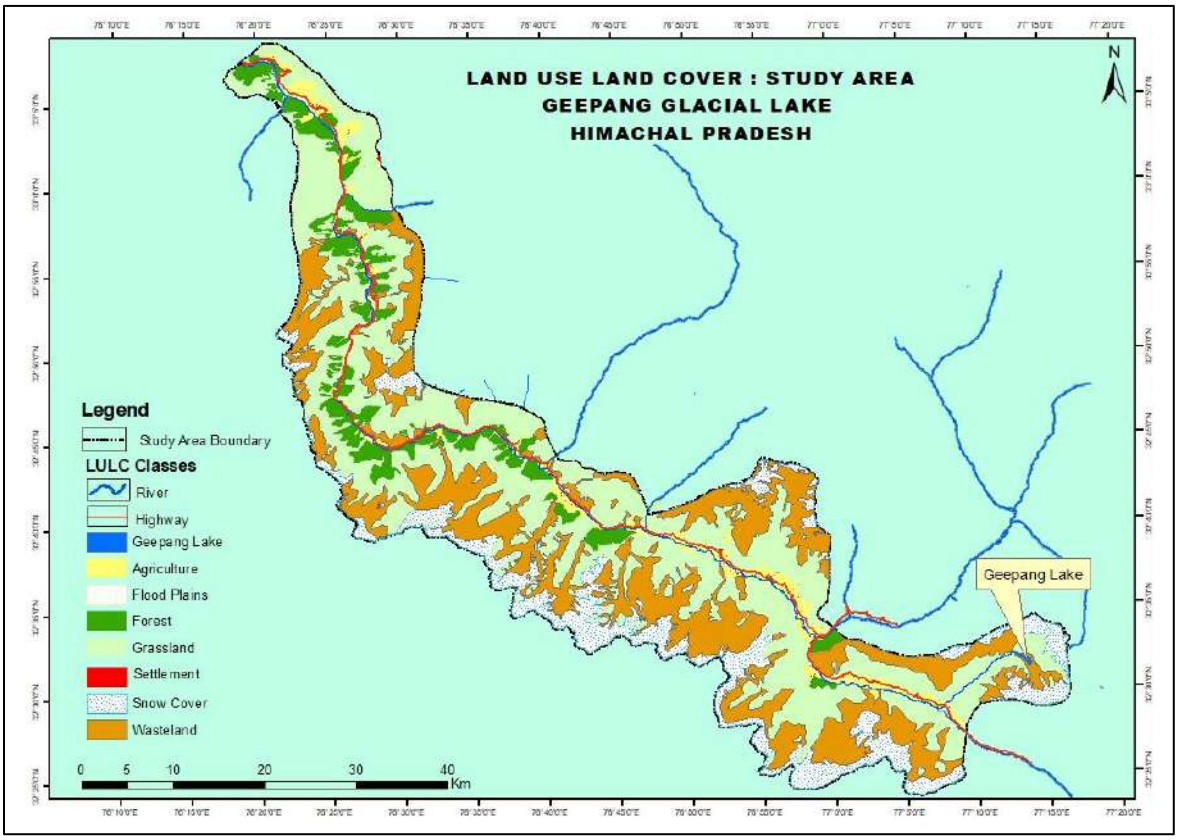

Fig. 3: Land Use Land Cover of Geepang Gath Glacial Lake.

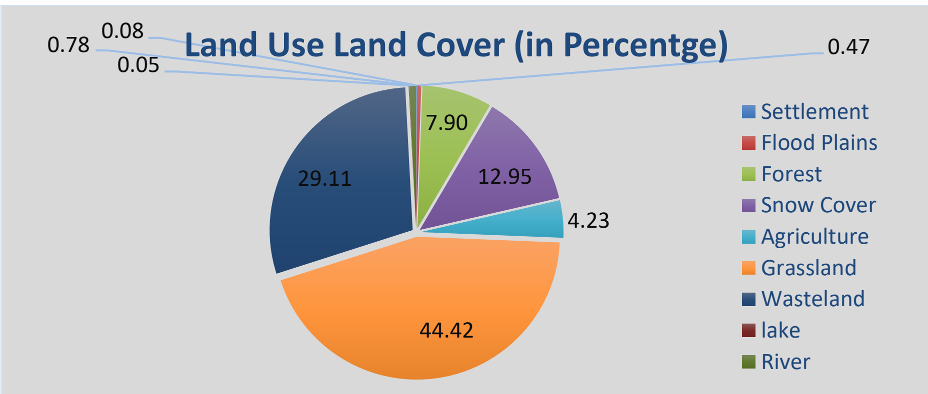

Fig. 4: Land Use Land Cover of Geepang Gath glacial lake in Percentage.

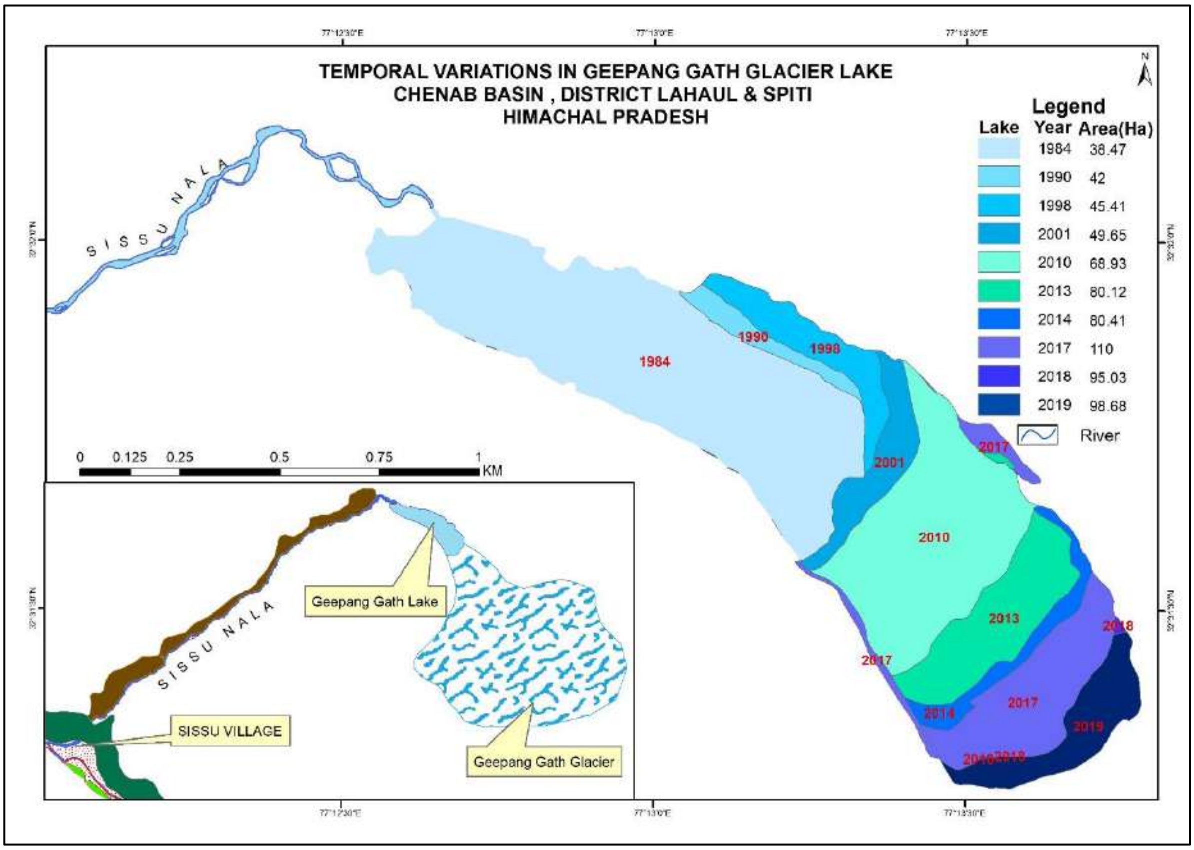

Fig. 5: Temporal variations of Geepang Gath glacial lake.

6. Formation of Moraine Dammed glacial lake at Geepang Gath glacier:

Geepang Gath is a glacier in the Chandra river basin on the right bank. The Sissu Nala originating from this glacier joins the Chandra River on its right bank near Sissu village in the valley. This glacier is located at an elevation of 4100 meters above mean sea level and the maximum and minimum altitude of the glacier are as 5728 meters and 4170 meters. At the snout of the glacier i.e. at the frontal part of the glacier, a lake has been identified which was also reported by Survey of India as per the Survey of India toposheets with 1:50,000 scale having a total area of 27 ha. (1975). This lake has been formed by virtue of the damming of the morainic material that is why this is called moraine dammed glacial lake or pro glacial lake as it is formed in the front part of the glacier. Thus glacial lake is defined as water mass existing in a sufficient amount and extending with a free surface in, under, beside, and or in front of a glacier and originating from glacier activities and/or retreating processes of a glacier. As per the Survey of India toposheet, the lake area has been mapped as 27 ha which when seen on the satellite data for its temporal variation over the years, it has been observed that the lake area varies 36.47 ha (1984) to 42 ha (1990) to 45.41 ha (1998) to 49.65 ha (2001) to 68.93 (2010) to 80.12 ha (2013) to 80.41 ha (2014) and 110 ha (2017) (Fig. 5). As per the satellite data analysis of 2018, the lake area has been found to be reduced to 95.03 ha which may be dewatering of the lake but again in 2019, the area of the lake has increased to 98.63 ha. The discharge of Sissu Nala is mainly dependent on this glacier.

Based on the field-based studies carried out by National Centre for Polar and Ocean Research (MoES) Govt. of India has carried out the bathymetric studies of the Geepang Gath Glacier Lake and the average lake depth has been estimated as 33.19 metres using Sonar method. Based on the lake area and the depth, the lake volume and Q_{max} was calculated using the following empirical relations.

$Q_{max} = 75\ (V/1000000)^{0.67}\ m^3/s$

$Q_{max} = 0.72\ V^{0.53}\ m^3/s$

$Q_{max} = 0.0048\ V^{0.896}\ m^3/s$

Qmax=0.00077 V1.017 m3/s

Qmax=75 V0.67 m3/s

Photo -1 : Bathymetry survey on Gepang Gath Lake using RCV boat fitted with echo-sounder and GPS

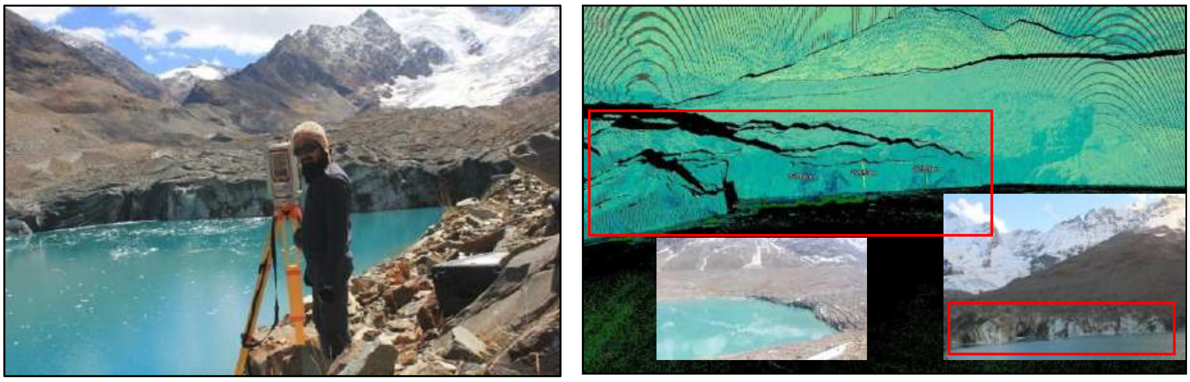

Photo -2 : TLS survey for measuring calving rate and glacier terminal height at water ice interface

Based on the spatial extent of the lake estimated for different areas, the lake volume it contains and if it bursts, the maximum discharge estimated is as per the Table:1 which is the highest in 2017 (835.43 m^3/s) and lowest in the year 1976 (325.98 m^3/s).

Table1: The lake Volume and Q_{max} was calculated using the following Empirical Relations

S.N.	Year	Area (Ha)	Volume (m^3)	Q_{max} in Hundred m^3/s	Q_{max} in Thousand m^3/s	Q_{max} in Ten thousand m^3/s	Q_{max} in ten Thousand m^3/s	Q_{max} in Million m^3/s
1	1976	27	896.27×10^4	3.25	3.48	0.81	0.90	3.41
2	1990	42	1394.19×10^4	4.38	4.40	1.20	1.41	4.58
3	1998	50	1659.76×10^4	4.92	4.83	1.41	1.69	5.15
4	2013	80.12	2659.59×10^4	6.75	6.20	2.15	2.73	7.07
5	2015	90.51	3004.49×10^4	7.33	6.61	2.40	3.10	7.67
6	2016	90.18	2993.54×10^4	7.31	6.60	2.39	3.08	7.65
7	2017	110	3651.47×10^4	8.35	7.33	2.86	3.78	8.74
8	2018	95.03	3154.53×10^4	7.57	6.78	2.51	3.25	7.93
9	2019	98.68	3275.70×10^4	7.76	6.92	2.59	3.38	8.13
h_{av} for 2017 = 33.1952 m								

7. Zonation along the immediate catchment in downstream of Geepang Gath glacier:

The flood zonation of downstream of Geepang Gath glacial Lake: 3 buffer Zones at 100 meter interval have been drawn from river (Fig: 6). Fig.7 Represents Quaternary deposits of the flood zonation of down Stream of Geepang Gath glacier.

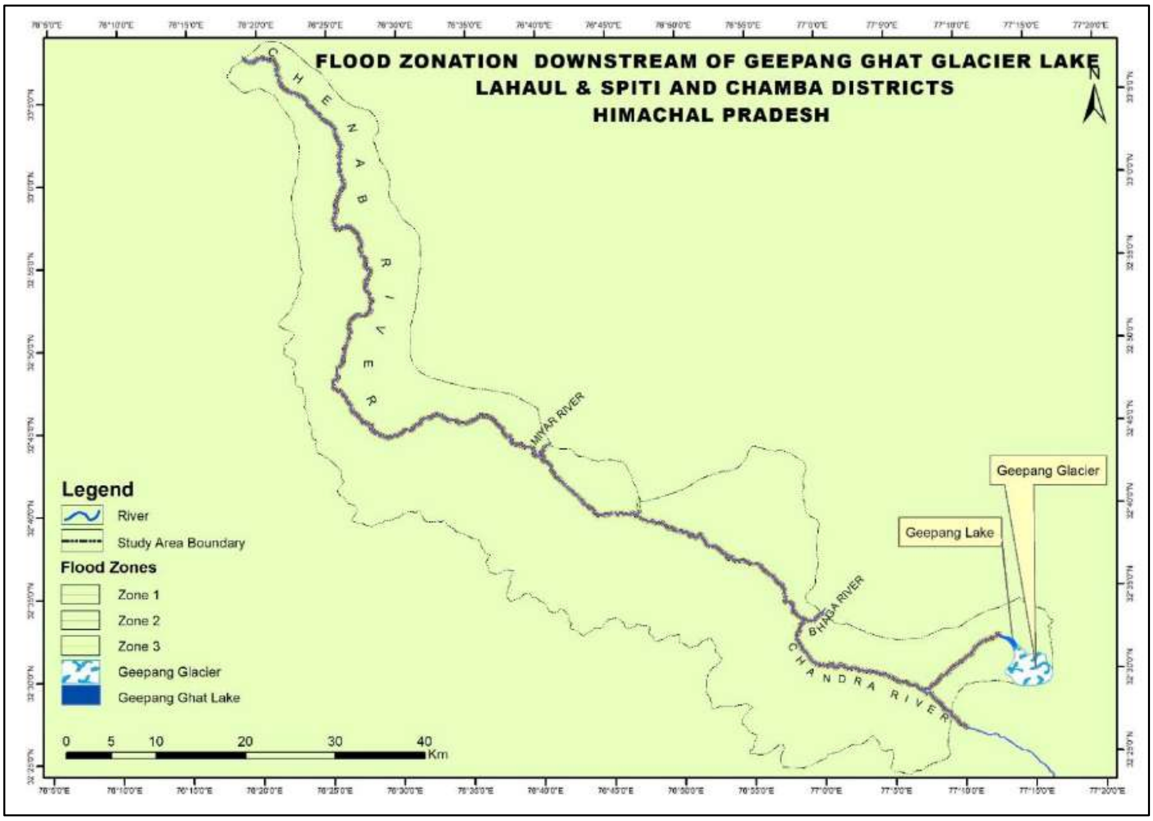

Fig. 6: Flood zonation downstream of Geepang Gath glacial lake.

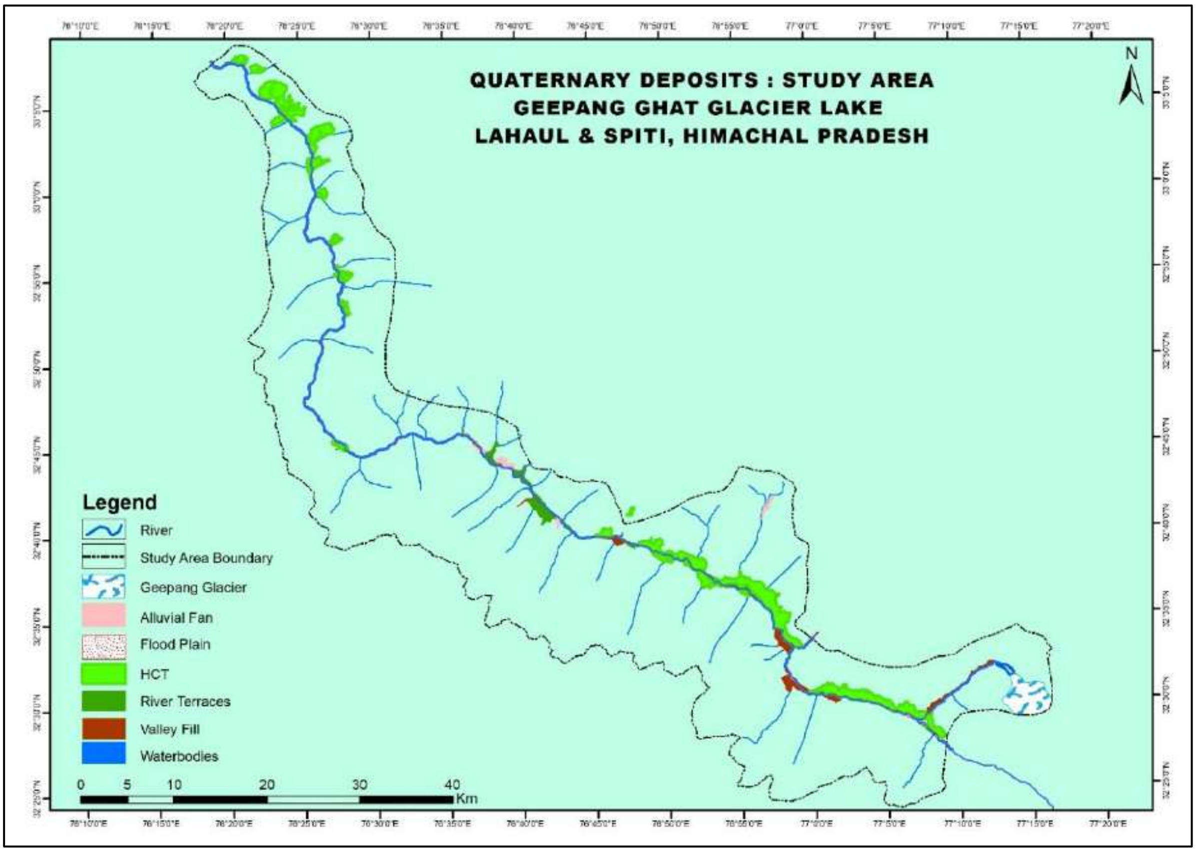

Fig. 7: Quaternary deposits of Geepang Gath glacial lake.

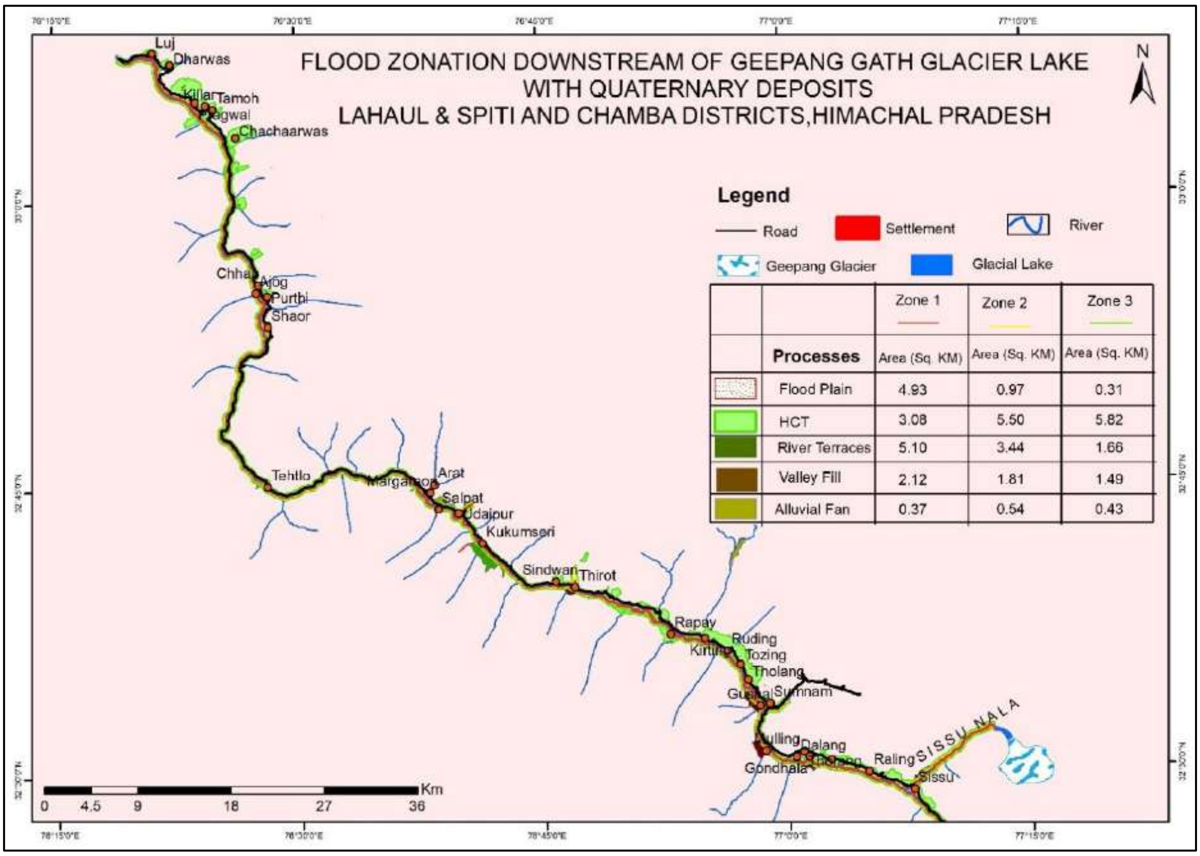

Fig. 8: Flood zonation downstream of Geepang Gath glacial lake.

Zone 1: Red Zone Area (Fig. 8):

- This zone lies between 0 to 100 meters from the river.
- River terraces constitutes 5.10 km^2 area followed by flood plains constitute of 4.93 km^2 area.
- Hill cut terraces has also been identified (3.08 km^2).
- Valley fills comprise of 2.12 km^2 area and alluvial fan being the lowest (0.37 km^2).

Zone II: Yellow Zone Area (Fig. 8):

- This zone lies between 100 to 200 meters from the river.
- Hill cut terraces have been identified as most dominant feature (5.50 km^2).
- River terraces constitute of 3.44 km^2 area followed by Valley fill constituting of 1.81 km^2.
- Flood plains comprises of 0.97 km^2 area and alluvial fan was lowest (0.53 km^2)

Zone III: Green Zone Area (Fig. 8):

- This zone lies between 200 to 300 meters from the river.
- Hill cut terraces have been identified as most dominant feature (5.82 km^2).
- River terraces constitute of 1.66 km^2 area followed by Valley fill constitute of 1.43 km^2 area.
- Alluvial fans comprise of 0.43 km^2 area and Flood Plain was lowest (0.31 km^2).

8 Segment wise mapping of flood zonation of downstream of Geepang Gath glacial lake: In the view of the larger coverage of the study area along the river course. The entire area has been studied in different segments depicting 3 buffer Zones i.e. Zone 1, Zone II and Zone III at 100 meter interval drawn from the river.

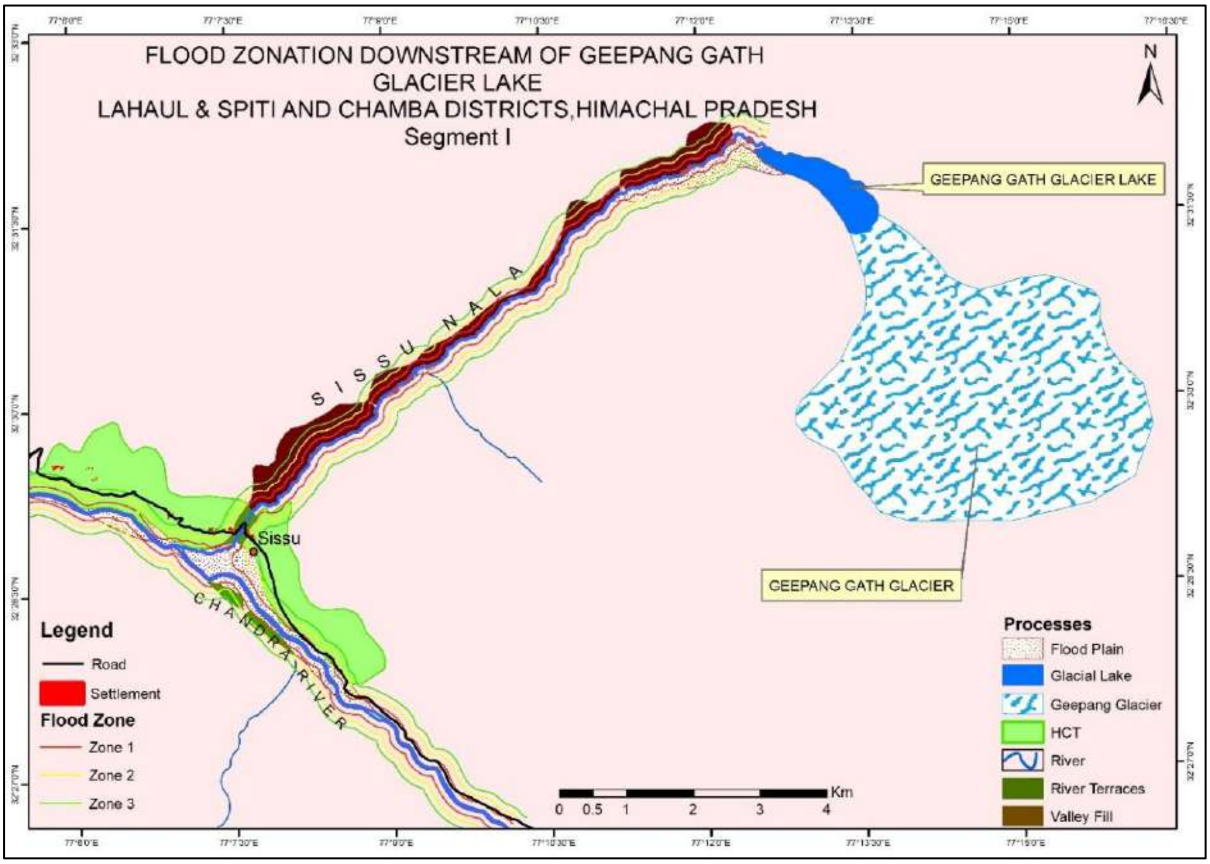

Fig. 9: Flood Zonation Downstream of Segment-I, Geepang Gath Glacial Lake.

8.1 Segment 1: 3 buffer Zones at 100 meter interval have been drawn from river (Fig. 9).

➢ **Zone 1: Red Zone Area:**

- Flood plains constitute of 1.38 km^2 area followed by Valley fills constitute of 0.92 km^2 area.
- Hill cut terraces have also been identified 0.21 km^2 area.
- Lowest among them was River terraces comprised of 0.14 km^2 area.

➢ **Zone II: Yellow Zone Area:**

- Valley fills have been identified as most dominant feature (0.71 km^2) followed by Hill cut terraces (0.60 km^2).
- Flood plains comprise of 0.58 km^2 area.
- River terraces constitute of 0.10 km^2 area.

➢ **Zone III: Green Zone Area:**

- Hill cut terraces have been identified as most dominant feature (0.65 km^2) followed by Valley fill constitutes 0.52 km^2 area.
- Flood plains comprise of 0.13 km^2 area.
- River terraces constitute of 0.04km^2 area.

- Total length of the road in this segment is 12.44 km. The affected length of roads under this segment in Zone 1 is 3.84 km, Zone II is 4.89 km and Zone III is 2.15 km.
- Sissu Village lies in Zone II and Zone III, there has been no habitation identified in Zone I.

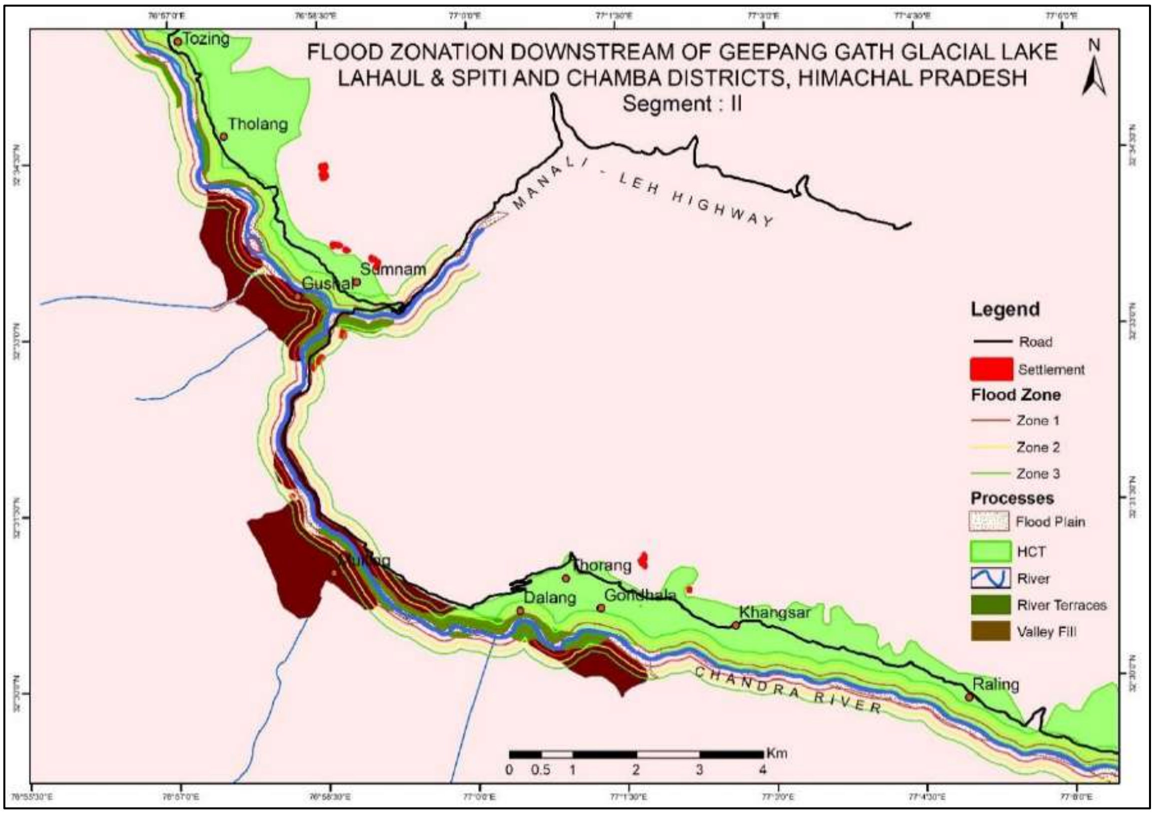

Fig. 10: Flood zonation downstream of Segment-II, Geepang Gath glacial lake.

8.2 Segment II: 3 buffer Zones at 100 meter interval have been drawn from river (Fig. 10).

- **Zone 1: Red Zone Area:**
  - Flood plains constitute 1.42 km^2 area followed by Hill cut terraces have also been identified 0.95 km^2 area.
  - River terraces constitute of 0.81 km^2 area.
  - Lowest among them was Valley fill comprised of 0.64 km^2 area.
- **Zone II: Yellow Zone Area:**
  - Hill cut terraces has been identified as most dominant feature (1.54 km^2) followed by Valley fills (0.85 km^2).
  - River terraces constitute of 0.53 km^2 area.
  - Flood plains comprise of 0.11 km^2 area.
- **Zone III: Green Zone Area:**
  - Hill cut terraces have been identified as most dominant feature (1.16 km^2) followed by Valley fills constitute of 0.83 km^2 area.

- River terraces constitute of 0.04km^2 area.
- Flood plains comprise of 0.01 km^2 area.

➢ Total length of the road in this segment is 28.21 km. The affected length of roads under this segment in Zone 1 is 5.04 km, Zone II is 1.66 km and Zone III is 3.08 km.

➢ There are few settlements along Manali – Leh National Highway, Gushal and Bha Garang etc. villages were identified in all three Zones got affected.

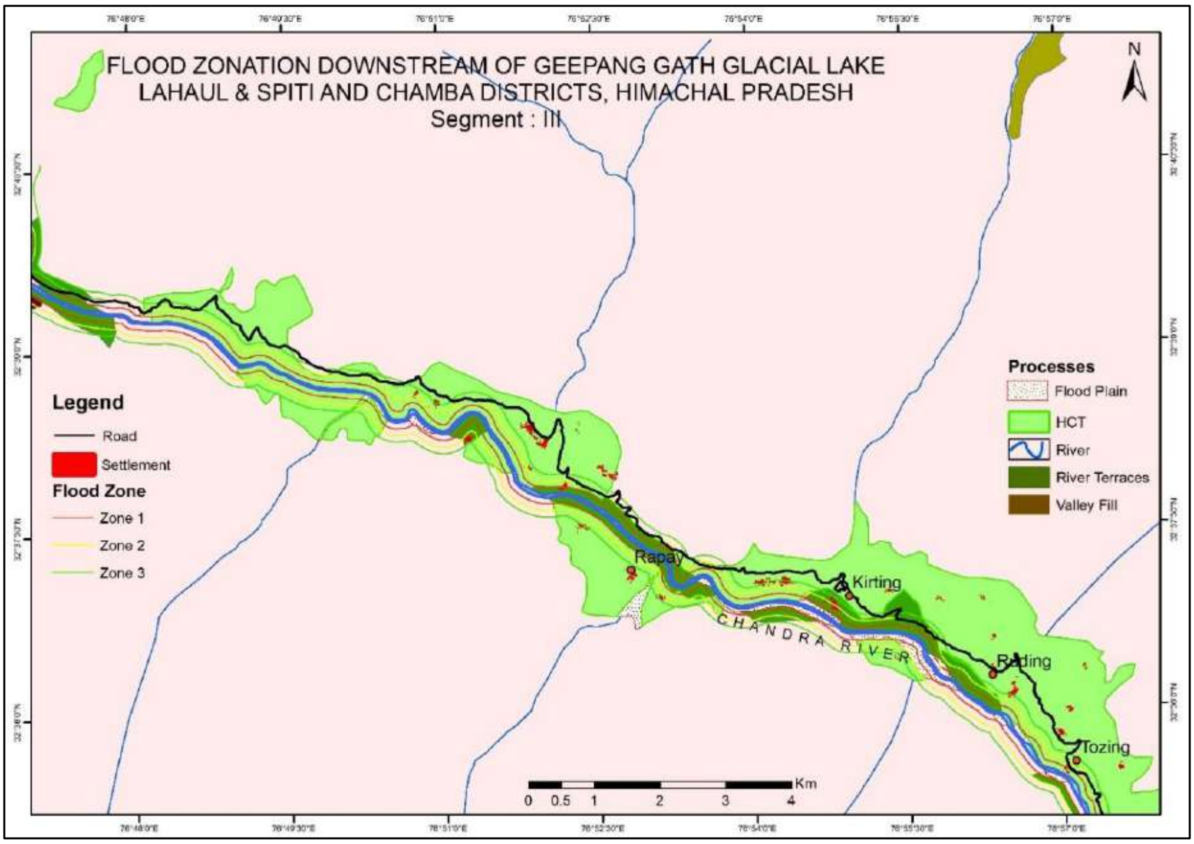

Fig. 11: Flood zonation downstream of Segment-III, Geepang Gath glacial lake.

8.3 Segment III: 3 buffer Zones at 100 meter interval have been drawn from river (Fig. 11).

➢ **Zone 1: Red Zone Area:**

- Flood plains constitute of 1.42 km^2 followed by Hill cut terraces have also been identified 0.95 km^2 area.
- River terraces constitute of 0.81 km^2 area.
- Lowest among them was Valley fill comprised of 0.64 km^2 area.

➢ **Zone II: Yellow Zone Area:**

- Hill cut terraces have been identified as most dominant feature (1.54 km^2) followed by Valley fill (0.85 km^2)
- River terraces constitute of 0.53 km^2 area.

- Flood plains comprise of 0.11 km^2 area.

➢ **Zone III: Green Zone Area:**

- Hill cut terraces have been identified as most dominant feature (1.16 km^2) followed by Valley fill constitutes 0.83 km^2 area.
- River terraces constitute of 0.04km^2 area.
- Flood plains comprise of 0.01 km^2 area.

➢ Total length of the road in this segment is 22.74 km. Affected Length of Roads under this segment in Zone 1 is 0.91 km, Zone II is 3.43 km and Zone III is 5.50 km.

➢ There are few settlements of villages Tozing, Rapay, Goruma etc. were identified in all three Zones those will be affected.

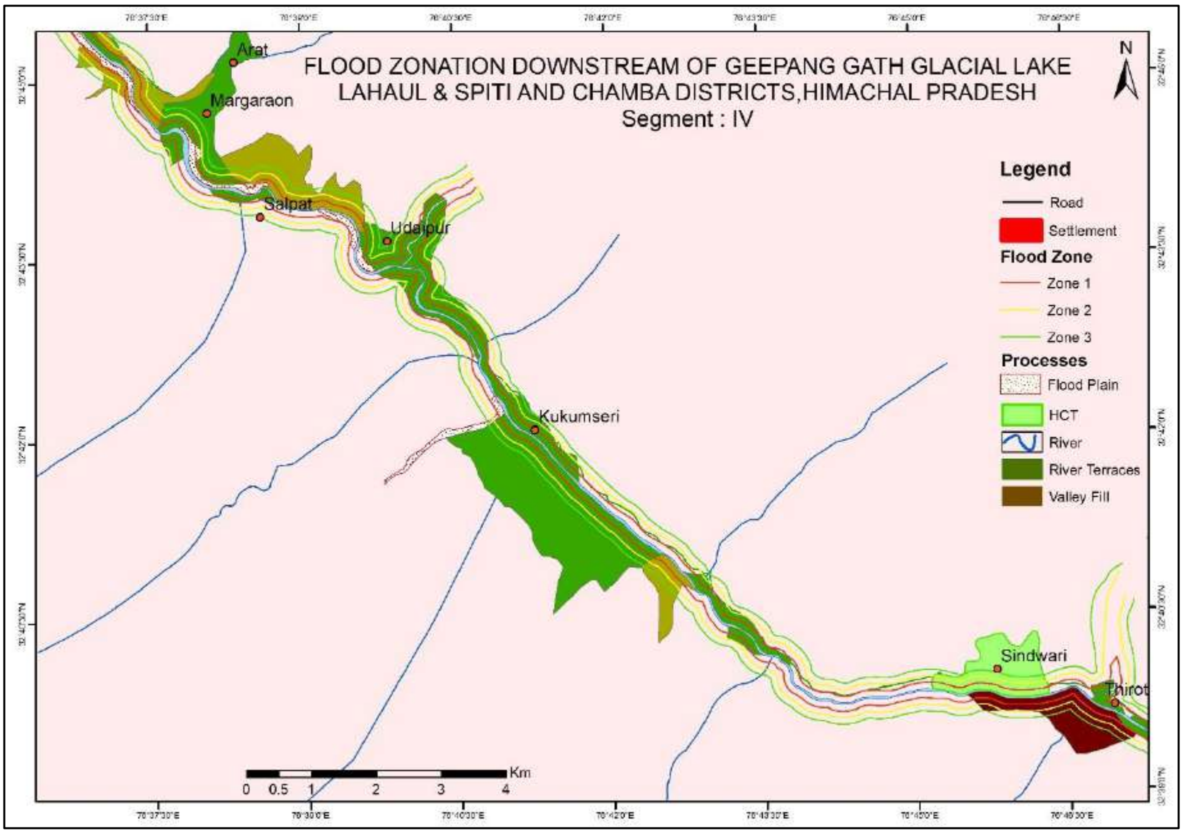

Fig. 12: Flood zonation downstream of Segment-IV, Geepang Gath glacial lake.

8.4 Segment IV: 3 buffer Zones at 100 meter interval have been drawn from river (Fig. 12).

➢ **Zone 1: Red Zone Area:**

- River terraces constitute of 2.10 km^2 area followed by Flood plains constitute of 0.48 km^2 area.
- Hill cut terraces have also been identified 0.18 km^2 area.
- Alluvial fan comprises of 0.36 km^2 area.

- Valley fill comprised of 0.25 km^2 area.

➢ **Zone II: Yellow Zone Area:**

- River terraces has been identified as most dominant feature 1.64 km^2 area followed by Alluvial fan comprises of 0.51 km^2 area.
- Valley fill (0.24 km^2) followed by Hill cut terraces (0.18 km^2)
- Flood plains comprises of 0.04 km^2 area.

➢ **Zone III: Green Zone Area:**

- River terraces have been identified as most dominant feature (1.07km^2) followed by Alluvial fan comprises of 0.40 km^2 area.
- Valley Fill constitutes 0.16km^2 area.
- Hill cut terraces constitutes 0.15km^2 area.
- Flood plains comprises of 0.01 km^2 area.

➢ Total length of the road in this segment is 22.20 km. The affected Length of Roads under this segment in Zone 1 is 7.26 km, Zone II is 10.94 km and Zone III is 2.51 km.

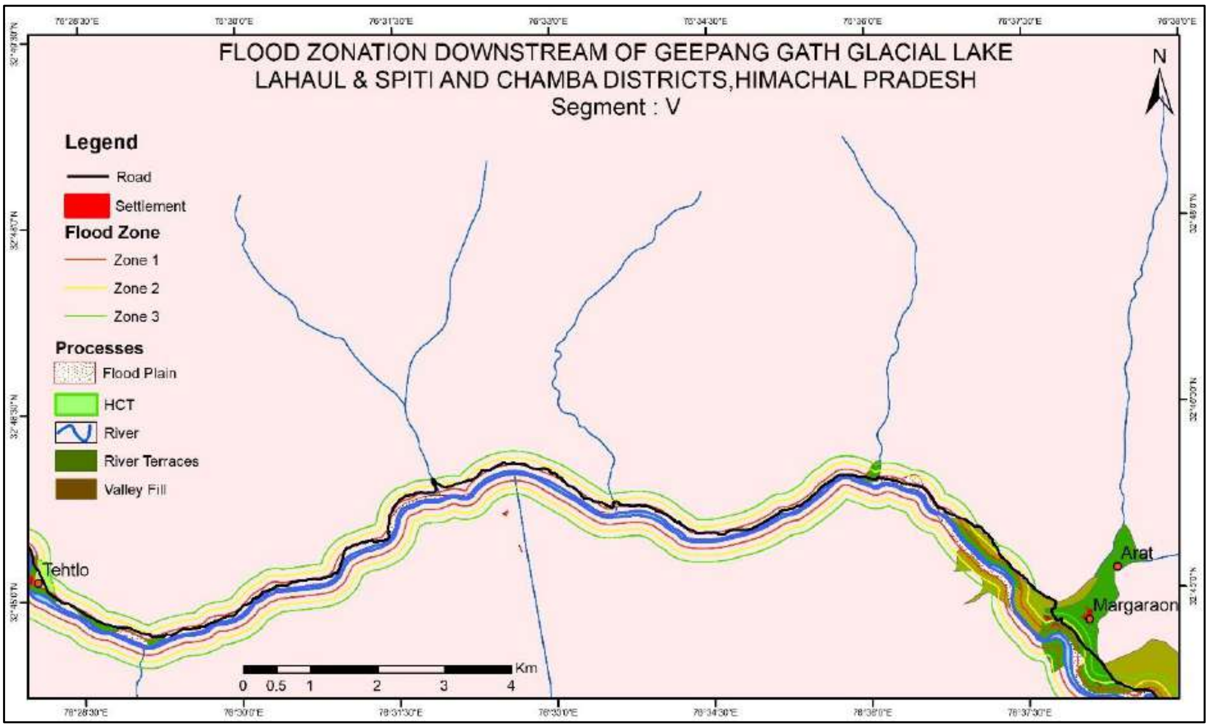

Fig. 13: Flood zonation downstream of Segment-V, Geepang Gath glacial lake.

8.5 Segment V: 3 buffer Zones at 100 meter interval have been drawn from river (Fig. 13).

➢ **Zone 1: Red Zone Area:**

- Flood plains has been identified 0.41 km^2 followed by km^2 has River terraces constitutes 0.23 km^2

- Hill cut terraces constitutes 0.08 km^2
- Lowest among them was Valley fill (0.02 km^2) and alluvial fan (0.01 km^2)

➢ **Zone II: Yellow Zone Area:**

- Hill cut terraces has been identified as most dominant feature (0.20 km^2) followed by Valley fill (0.02 km^2)
- Flood plains comprises of 0.09 km^2
- Both Alluvial fan and River terraces comprises of 0.03 km$^{2.}$

➢ **Zone III: Green Zone Area:**

- Hill cut terraces has been identified as most dominant feature (0.16 km^2) followed by Flood plains comprises of 0.04 km^2
- Alluvial fan constitutes 0.03 km^2
- River terraces constitutes 0.014km^2

➢ Total length of the road in this segment is 21.06 km. The affected Length of Roads under this segment in Zone 1 is 13.07 km, Zone II is 7.04 km and Zone III is 0.94 km.

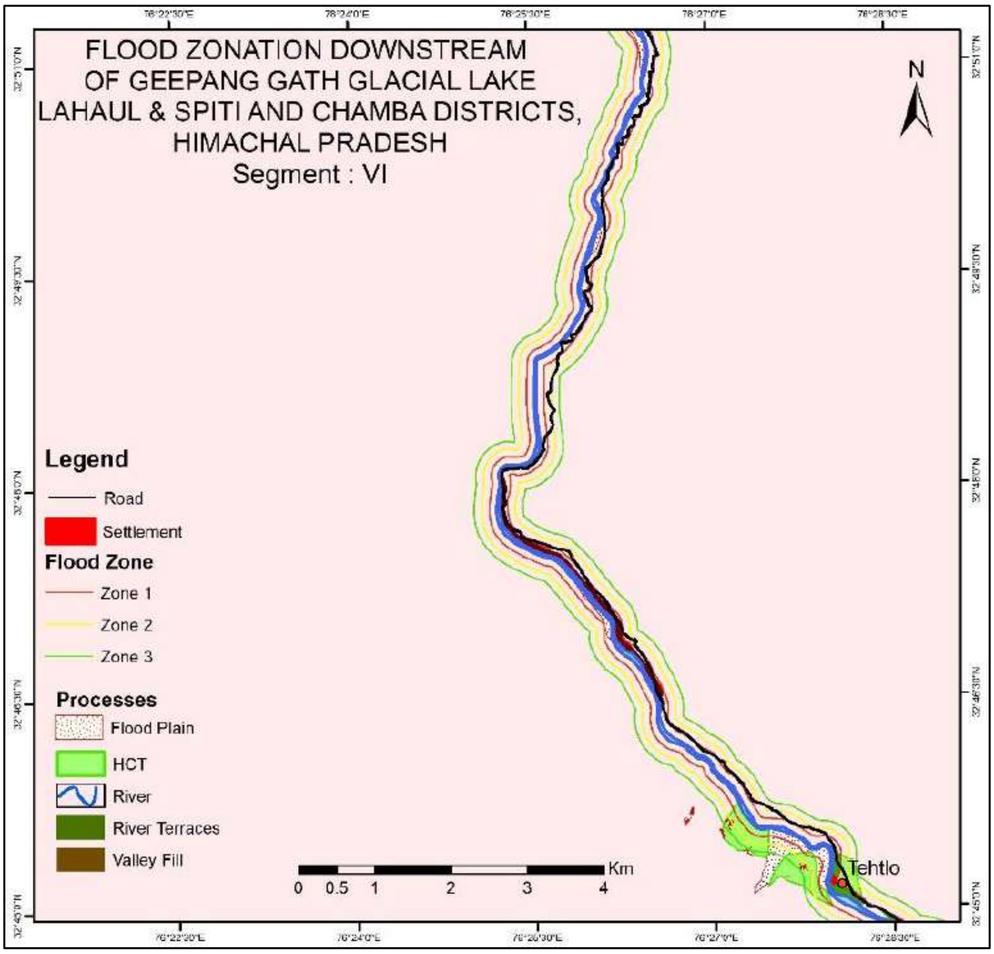

Fig. 14: Flood zonation downstream of Segment-VI, Geepang Gath glacial lake.

8.6 Segment VI: 3 buffer Zones at 100 meter interval have been drawn from river (Fig. 14).

- **Zone 1: Red Zone Area:**
  - Valley fill Constitutes 0.27 km^2 area followed by Flood plains has been also identified 0.19 km^2 area.
- Total length of the road in this segment is 15.79 km. The affected Length of Roads under this segment in Zone 1 is 10.47 km, Zone II is 4.81 km and Zone III is 0.44 km.

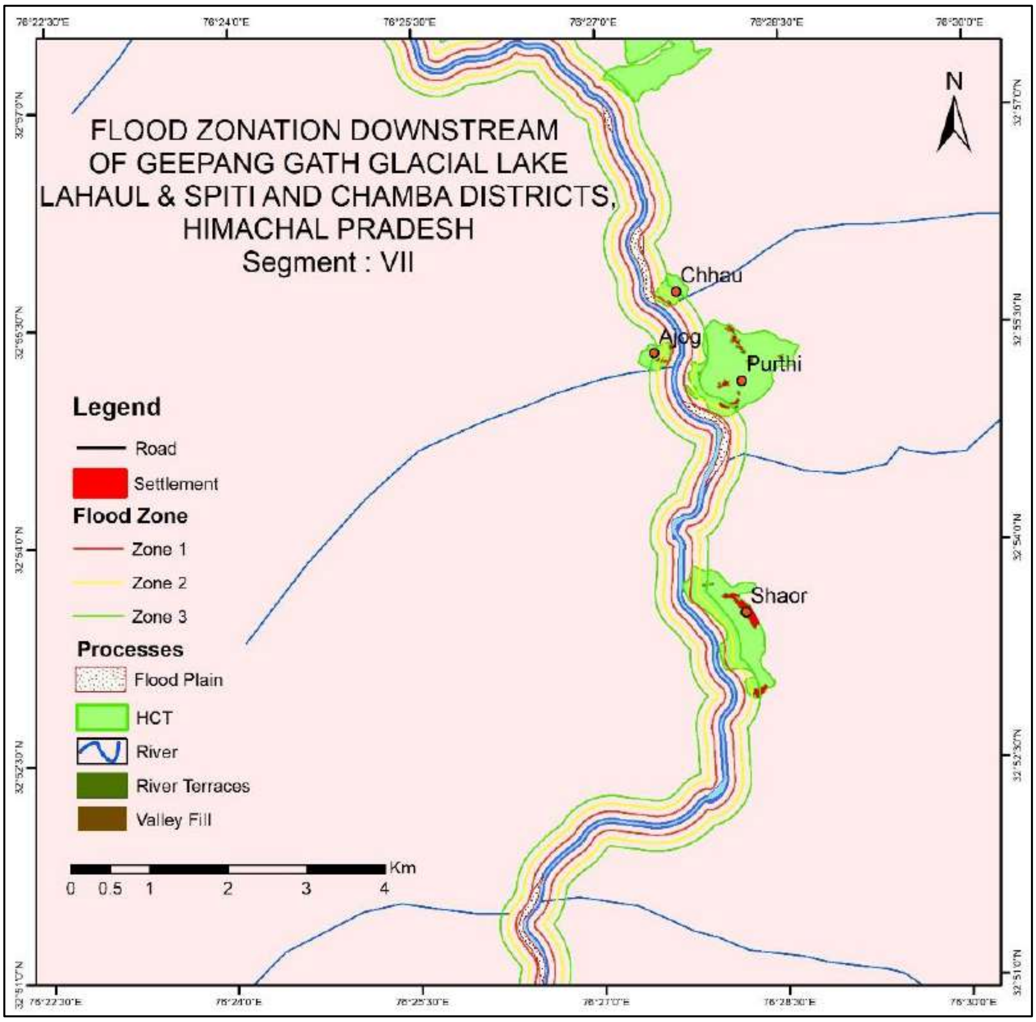

Fig. 15: Flood zonation downstream of Segment-VII, Geepang Gath glacial lake.

8.7 Segment VII: 3 buffer Zones at 100 meter interval have been drawn from river (Fig. 15).

- **Zone 1: Red Zone Area:**
  - Flood plains constitutes 0.37 km^2 area followed by Hill cut terraces has been also identified 0.46 km^2 area.
  - River terraces constitute of 0.08 km^2 area.

- Lowest among them was Valley fill comprised of 0.018 km^2 area.

➢ **Zone II: Yellow Zone Area:**

- Hill cut terraces has been identified as most dominant feature (0.22 km^2) followed by River Terraces (0.14 km^2)
- Flood plains comprises of 0.016 km^2

➢ **Zone III: Green Zone Area:**

- Hill cut terraces has been identified as most dominant feature (0.35 km^2) followed by River terraces constitutes 0.043 km^2 area.

➢ Total length of the road in this segment is 17.17 km. Affected Length of Roads under this segment in Zone 1 is 1.36 km, Zone II is 8.48 km and Zone III is 1.78 km.

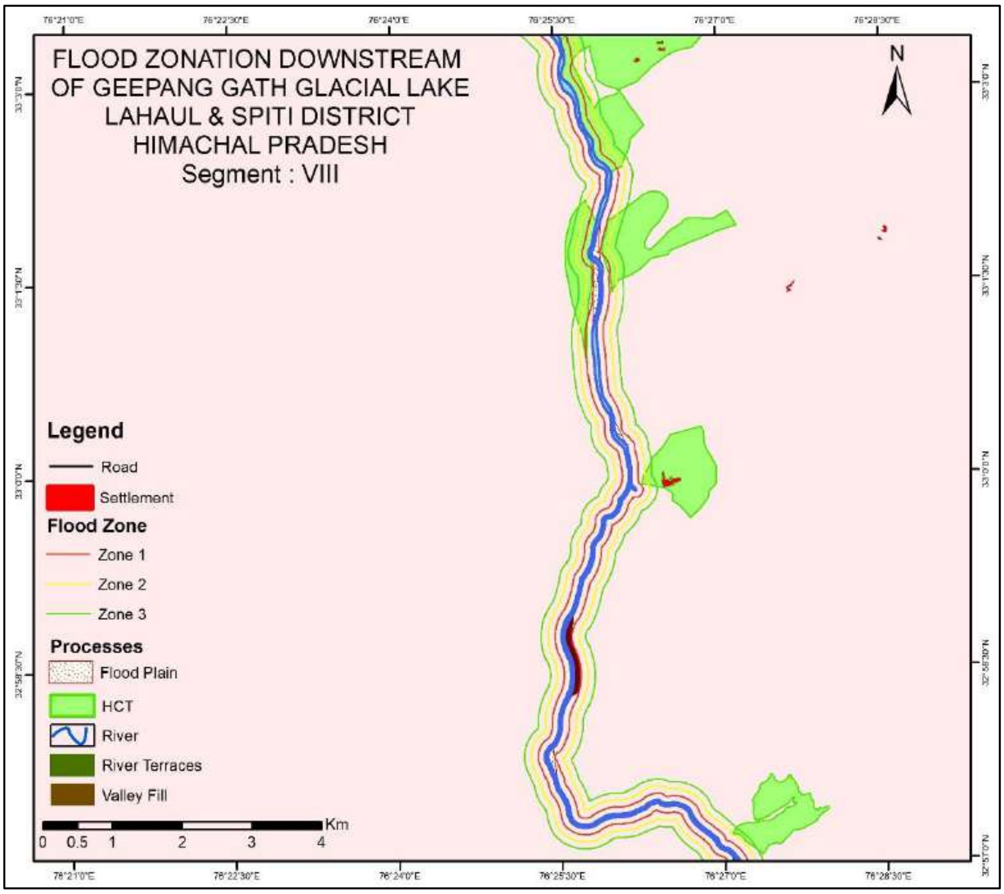

Fig. 16: Flood zonation downstream of Segment-VIII, Geepang Gath glacial lake.

8.8 Segment VIII: 3 buffer Zones at 100 meter interval have been drawn from river (Fig. 16).

➢ **Zone 1: Red Zone Area:**

- Hill cut terraces have been identified 0.31 km^2 area followed by Flood plains constitute of 1.12 km^2 area.

- Lowest among them was Valley fill comprised of 0.09 km^2 area and River terraces constitute of 0.02 km^2 area.

➢ **Zone II: Yellow Zone Area:**

- Hill cut terraces has been identified as most dominant feature (0.48 km^2)
- Flood plains comprise of 0.0004 km^2 area.

➢ **Zone III: Green Zone Area:**

- Hill cut terraces have been identified as most dominant feature (0.44 km^2).

➢ Total length of the road in this segment is 11.47 km. The affected length of roads under this segment in Zone 1 is 8.08 km, Zone II is 2.84 km and Zone III is 5.44 km.

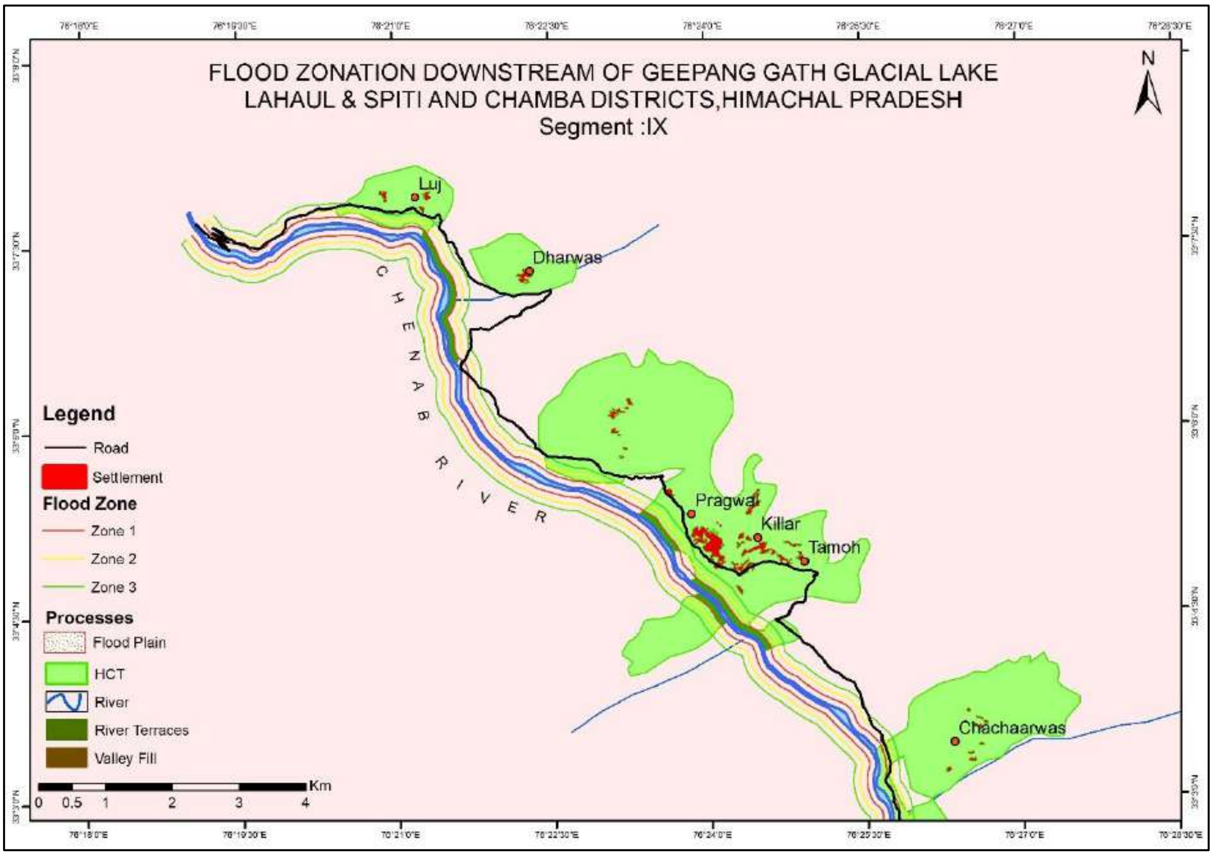

Fig. 17: Flood zonation downstream of Segment-IX, Geepang Gath Glacial Lake.

8.9 Segment IX: 3 buffer Zones at 100 meter interval have been drawn from river.

➢ **Zone 1: Red Zone Area:**

- River terraces constitute of 0.49 km^2 area followed by Flood plains have also been identified 0.003 km^2 area.

➢ **Zone II: Yellow Zone Area:**

- Hill cut terraces have been identified as most dominant feature (0.42 km^2)

➢ **Zone III: Green Zone Area:**

- Hill cut terraces have been identified as most dominant feature (0.58 km^2)

- Total length of the road in this segment is 18.92 km. The affected length of roads under this segment in Zone II is 2.62 km and Zone III is 2.01 km.

9. Concluding Remarks:

Geepang Gath glacial lake showed increasing trend, as the Geepang Gath glacier receding at faster rate. For flood zonation of downstream of Geepang Gath glacial lake, 3 buffer zones at 100 meter interval has been drawn from river (Fig: 6). Fig.7 Represents Quaternary Deposits of the Flood Zonation of down Stream of Geepang Gath Glacier. In Zone 1 (Red Zone Area), lies between 0 to 100 meters from the river Chandra includes River terraces constitutes 5.10 km^2 followed by flood plains constituting 4.93 km^2. It also comprised of Hill cut terraces (3.08 km^2), Valley fill (2.12 km^2) and alluvial fan being the lowest (0.37 km^2).In Zone II (Yellow Zone Area) which lies between 100 to 200 meters from the river Hill cut terraces have been identified as most dominant feature (5.50 km^2) followed by River terraces (3.44 km^2), Valley fill (1.81 km^2), flood plains (0.97 $km^{2)}$ and alluvial fan was lowest (0.53 km^2). Last Zone is Zone III (Green Zone Area: 200-300 meters away from the river Chandra) comprised of Hill cut terraces has been identified as most dominant feature (5.82 km^2) followed by River terraces (1.66 km^2), valley fills (1.43 km^2), alluvial fans (0.43 km^2) and flood Plains was lowest (0.31 km^2).

These three zones have been studied in great details along with the segment in which the study area has been divided by virtue of its coverage. Each zone and each segment signifies the likely impact on its land use land cover by virtue of the heavy discharge in the river course in case the lake burst. The total volume of discharge has also been worked out using the variable empirical relations considering the average depth of the lake based on the mathematically studies carried out physically by National Centre for Polar and Ocean Research (NCPOR), Goa. The maximum discharge has been estimated 835.43 m^3/s in 2017 and minimum in the year 1976 (325.98 m^3/s).

The present study has made it possible to make an attempt to visualize the impact of flood water in case of bursting the Geepang Gath glacial lake and its damage on different landforms unit along the river course. There were few settlements identified in the red zone area. The highway along the river Chandra also got washed away. It also affects the agricultural land, forest and grassland within 300 meters of the flood zones of the study area. Based on the satellite data interpretation there do not seem to be any threat from the Geepang Gath Lake at present but in future it may burst. So monitoring and evaluation should be done time to time. This would help in making a prior assessment of the damages likely to occur and thereby planning accordingly in the light of the Himalayan conditions.

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