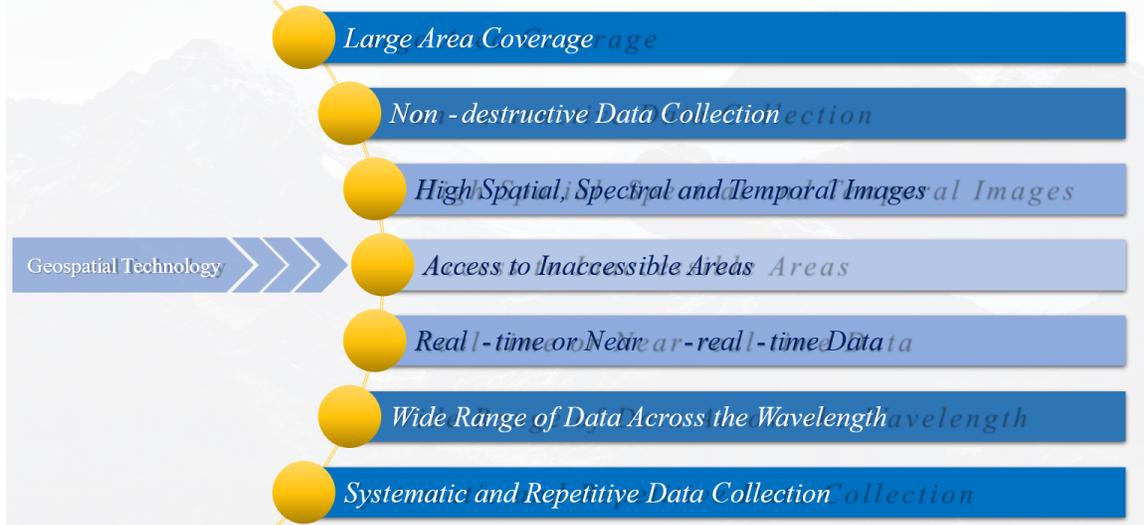


REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lec 26 a: Glacial Lake Vulnerability Assessment Part A

Hello everyone, welcome to Lecture 26. Today, we will talk about the Glacial Lake Vulnerability Assessment. This lecture belongs to module 7, and today we will learn about the Vulnerability Assessment. So, let us start with the basics: what is a glacial lake? So, a glacial lake is a body of water with its origin from glacier activities. They are formed when a glacier erodes the land and then melts, filling the depression created by the glacier. And here you can see some examples so that you can understand what we exactly mean by glacier lakes and these glacial lakes are often dammed by the moraines or ice. So, here you can see an example of moraines. So, here is the moraine that is holding this particular water, which is coming from these glaciers, and in this case, you can see some of the ice; they are acting as a barrier, and then this water will be accumulated. So, these are the two different types of glacier lakes, and here is another example where glacier flow is in this direction; here it starts melting, and the depression is getting filled with glacier meltwater.

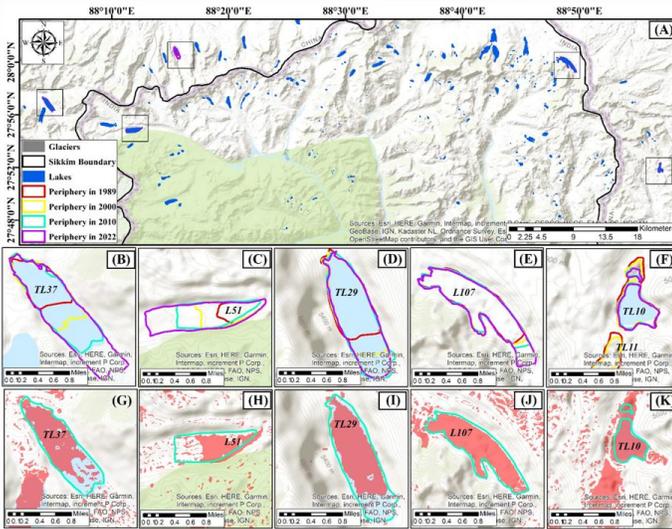
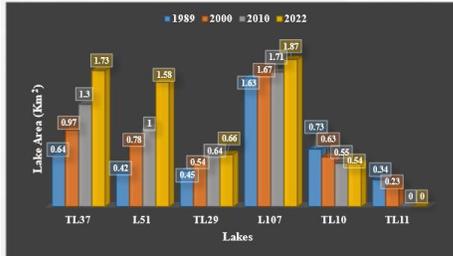


So, a glacial lake is a body of water that originates from glacial activities. These lakes frequently form at the terminus or foot of a glacier. However, they can also develop on the glacier surface, inside the ice itself, or underneath it. So, I hope you remember the different types of glaciers: supraglacial and other forms that were there. So, here this is one of the types with changing climatic conditions; glaciers are retreating rapidly, leading to increased freshwater accumulation in glacial lakes. These are again the different types of glacier lakes from different locations, and the glacier lakes have grown rapidly around the world in the last three decades, showing the impact of increased meltwater. So, ultimately, the water that is coming to these glacier lakes is from the melt, and it is because of the changing climatic conditions. We have also understood in the previous few lectures how important it is to understand the process, the associated hazards, and how they can impact our livelihood. This is one example that shows the importance of monitoring glacial lakes. So, this is from South Lhonak and this lake, particularly, you see there was a breach here during the GLOF event. So, this is the before breach, and this is the after breach. So, once we have the advantage of satellite images, we can have continuous monitoring of the given glacial lakes. So, let us try to understand the importance of remote sensing in cryospheric hazards. So, particularly, it has a large aerial coverage, which is very, very important. Then the data information that we are gathering through remote sensing is non-destructive in nature. That means it is not disturbing the area that is acquired by the sensor. So, we are not disturbing the sample. With advancements in remote sensing technology, we have high spatial, spectral, and temporal images, as well as access to inaccessible areas, which is another advantage of remote sensing data. Then, real-time or near-real-time datasets are also available.

Temporal Changes in the Glacial Lake Area

Results from Sikkim Himalaya

Lake	Areal change rate b/w 1989 & 2022
TL37	2.7
L51	3.76
TL29	1.47
L107	1.15
TL10	0.74
TL11	Vanished



So, we see different images available in the archives of the corresponding space agency. So, these datasets can be referred to in studying these kinds of temporal changes in the glacial lake boundaries. A wide range of data across the wavelength shows that higher altitudes have cloud cover. So, optical datasets are not useful; then we move towards the microwave remote sensing domain, which can be utilized here. Then comes systematic and repetitive data collection.

If you want to correlate or go for change detection, these remote sensing satellite images are very useful because they are in the same format and also have geotagged locations that help us analyze the temporal changes in a given area, particularly in this case, glacial lake boundaries. So, here you can see this is an example from the Sikkim Himalayas. So, particularly here we have analyzed the boundaries of the Glacial Lake from 1989 to 2022. And, here you can see that different boundaries are marked. So, here the red color is the base map for us. It is 1989, and the purple is 2022. And you see many of them are increasing in size. Some of them have vanished. This particular graph can be used to analyze which of these lakes is growing rapidly. And here you can see this table; it says TL11, and if you refer to my paper, you will understand which one is the TL11.

So, the link is given at the end of this lecture. So, this particular glacial lake has vanished. So, it is not always growing. So, some of the glaciers are not melting rapidly; some of them are melting, and as a result, in the lower reaches, you will have the formation or vanishing of glacial lakes. So, to understand it thoroughly. Let us go through this basic detail the accumulation of glacier meltwater, unable to flow naturally due to barriers like ice dams, bedrock, or moraines, results in the creation of glacial lakes. Due to the changing climatic conditions, retreating glaciers are leading to the formation of more glacial lakes and an increase in their size. The failure of such moraine dams through

breaching or overtopping suddenly releases a large amount of water downstream. A sudden release of meltwater from a glacial lake resulted in a catastrophic flood known as GLOF. Due to the changing climatic conditions and topography, glacial lakes are more susceptible to GLOF. So, here you can see that this particular image shows how devastating a lake failure can be. So, on October 4, Sikkim in northeast India experienced a devastating glacial lake outburst flood triggered by intense rainfall that caused the glacial lake to rupture. This led to a sudden rise in the Teesta River's water level of approximately 20 feet, resulting in extensive destruction of infrastructure, homes, and loss of lives. The resulting flash floods surged downstream and struck the Teesta. The III dam at Chungthang was demolished around midnight, within minutes before the dam's gate could be opened. So, this is an example from the Sikkim Himalayas. And this particular slide will help you understand the need for the vulnerability assessment of these lakes. So, this is the threat to human settlements: destruction of infrastructure, economic disruption, and environmental impact. So, these are the major components why we need the vulnerability assessment. And this glacial lake vulnerability can be linked to the changing climatic conditions, which call for an early warning system for a given lake that is vulnerable and is rapidly increasing its aerial extent.

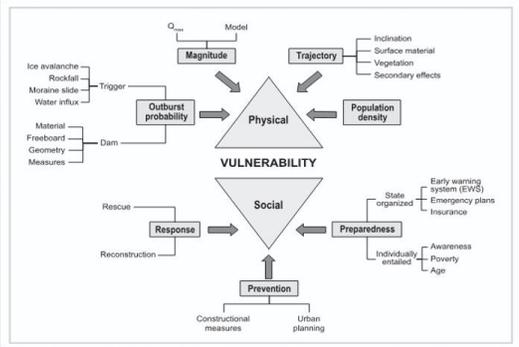
So, here you can see that the glacial lake vulnerability refers to the susceptibility of glacial lakes to outburst floods, which are sudden releases of large volumes of water from these lakes. So, here you can see the examples. These floods can cause widespread damage to infrastructure and lives downstream, particularly in high-altitude regions like the Himalayas. Now, let us try to understand why this vulnerability assessment is important. So, let us go over the minute details.

Indicators of Vulnerability



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Vulnerability indicators are measurable factors used to assess the degree to which a system, community, or environment is susceptible to harm from hazards. (Birkmann, J. 2006)



For Example:

- Lake size
- Moraine
- Slope
- Stability
- Proximity to Settlement Area

adaptation strategies. Implementing adaptation measures in the short term can help mitigate the risk. A thorough evaluation of both physical and socioeconomic risks associated with climate change in the region is required. Vulnerability assessment is an important step to understand and reduce the dangers caused by glacial lake outburst floods. I have covered the GLOF in detail in the previous lecture; vulnerability assessment helps to pinpoint which areas are most likely to be impacted by the GLOF, considering factors like the size of the glacial lake, the stability of the dam, and the presence of settlements and infrastructure in the downstream areas.

It assesses the potential consequences of a GLOF, including the extent of flooding, damage to infrastructure, and the potential for loss of life. Vulnerability assessment is the process of identifying, quantifying, and prioritizing the vulnerabilities in a system. Vulnerability is defined as the extent to which climate change can damage or harm a system. It is a function of both sensitivity to climate and the ability to adapt to new conditions. So, it is not always going in the negative direction; because of this changing climatic condition, the lake or the area can adapt to a new condition that will be a new normal condition.

For the vulnerability analysis, various satellite products, including DEMs, are used. A land use land cover map (LULC) of the study areas showing in-situ observations is serving as a driving factor for the vulnerability analysis. So, what are the different indicators of vulnerability? So, we have a physical indicator, then we have an economic indicator. Social indicators, environmental indicator, institutional indicators. So, in physical indicators, the location of settlements in hazard-prone areas is studied, along with the quality of housing and infrastructure and accessibility to emergency services that come under the physical indicators.

In economic indicators, the income levels, employment rates, agriculture, and tourism will be present. In social indicators, population density, age and gender distribution, education and literacy rates, health status, and access to healthcare are the components of social indicators. When we talk about the environmental indicators, we have degradation of natural resources, deforestation and land use changes, water availability, and the quality of the water that is available to the people. Then come the institutional indicators: disaster preparedness and response, availability of early warning systems, governance, and policy effectiveness. How the government is responding or how a particular agency is responding to this disaster.

So, the vulnerability indicators are measurable factors used to assess the degree to which a system, community, or environment is susceptible to harm from hazards. So, here you can see the different indicators mentioned. For example, the lake size, moraine, slope, stability, and proximity to the settlement area can be Indicator of glacial lakes. The physical vulnerability refers to the degree to which a location is at risk from a potential

event. This risk is influenced by the nature of the hazard, such as a glacial lake outburst, as well as the event's magnitude and its likelihood of occurrence.

The physical vulnerability indicators are the magnitude, lake outburst probability, trajectory, and population density. Social vulnerability arises when unfavorable social conditions increase the risk to an individual's life or livelihood from specific and identifiable events related to health, the environment, or society. It is commonly assessed using an index that combines various social indicators. So, here when we talk about social vulnerability in glacial lake vulnerability assessment, we have population exposure. Socioeconomic status, access to infrastructure, social demographics, and livelihood dependence.

So, these are the indicators: the social indicators. Then, the components of social vulnerability include preparedness, prevention and the response. So, in preparedness, it refers to the state of being prepared as an individual or a community in a disaster. Prevention refers to measures taken to avoid or minimize the adverse impact of hazards and can be divided into structural and non-structural measures.

And the response means the capability to recover from a natural disaster, including immediate reaction and long-term coping with such an event. So, here we are talking about preparedness, prevention, and response in general, but now you can relate it to glacial lake vulnerability. So, when we talk about the glacial lake vulnerability analysis method, So, we have remote sensing and GIS-based mapping; here, the multi-temporal satellite data are used for lake delineation and change detection, as well as many other techniques like classification NDVI that can be used to identify or precisely mark the boundaries of the glacial lake. Then comes the field observation and validation because whatever we extract from remote sensing data has to be validated in the field; only then will you be confident about your results. Topographic and bathymetric analysis, since we are talking about the glacial lake.

The surface extent is one thing, but you also need to have an understanding of the volume of water that is stored in the glacier lake. For that, the bathymetric analysis is very, very important. Then comes the hydrodynamic and GLOF modeling that we saw in the previous lecture. Then comes the risk and vulnerability indexing. And then, climate change impact assessment: how and why we are experiencing these kinds of natural lake disasters.

So let us try to understand the risk indexing for glacial lakes. So, risk indexing for glacial lakes is important for systematically assessing and managing the hazards associated with glacial lake outburst floods. Due to climate change and global warming, glaciers retreat and melt, and the water accumulates in glacial lakes, which are held by moraines or an ice dam structure that poses the potential for sudden catastrophic flooding. By using the

risk indexing, it becomes possible to systematically identify the glacial lakes that are prone to outburst and to prioritize these for monitoring from this remote sensing data set or from field investigation. This proactive approach is crucial for minimizing loss of life and saving property.

It also assesses the development of early warning systems because that will be a part of early warning systems and long-term climate adaptation strategies, making it a crucial tool in mitigating the impacts of glacial lake hazards in vulnerability analysis. So, the factors which are associated with the risk assessment of the glacial lakes. So, here we have the size of the glacial lake. Type of the glacial lake, change in size of the glacial lake over time, stability of lakeside slope.

Then comes the upstream of the glacial lake. What is the condition of the glaciers? So, the distance from the snout to the glacial lake, and the slope from the snout to the glacial lake. Glacial lakes in the vicinity are connected within 1 kilometer in the same valley. So, how many glacial lakes are there that are connected? How many glaciers are feeding into a particular lake? These things are very, very important. Then, downstream of Glacier Lake, the distance to the nearest habitation is likely to be affected, along with the distance from the nearest dam and the distance from the nearest bridge. So, what could be the impact of catastrophic flooding if this glacier lake fails? So, that can be seen downstream of the glacier lake.

Then other parameters like historical GLOF events. Seismicity in that particular area will help you understand how vulnerable your glacial lake is to the GLOF. The factors that are associated here are the size of the glacial lake and the type of the glacial lake, so let us see them one by one. Over time, the lake changes with respect to stability of the lakeside slope, the distance from the snout to the glacial lake, the slope from the snout to the glacial lake, the connected glacial lakes within 1 kilometer, and the distance to the nearest habitation likely to be affected. Distance from the nearest dam, then distance from the nearest bridge, because these are the things that are very critical after the flooding event; we have to have communication to that particular area.

So, the criteria for identifying the potential GLOF are. So, the potentially dangerous glacial lakes can be identified through field investigation, analysis of processes, and records of past events if a particular lake has a history of GLOF. Assessment of the geomorphological and geotechnical characteristics of the lake and its surroundings. So, here we are basically talking about the moraines.

Evaluation of other physical conditions. So, the lake water level is rising. Then the lake position and then the dam condition and the moraine condition. The mother glacier conditions whether it is having the impact of climate change; then you can expect more meltwater in a glacier lake. Then surrounding physical conditions, such as the nearest

rockfall or snow avalanches, seismicity or new tectonic activities, climate shift, newly formed moraines, and sudden glacier avalanches near well-developed lakes, will trigger this. So, these are the different criteria by which we evaluate the vulnerability of glacial lakes.

So, with this, I will end part 1 of this lecture, and we will continue this in the next lecture. Thank you.