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Review Article

ASSESSING THE IMPACT OF CLIMATE CHANGE ON GLOF: A STUDY OF SIKKIM IN EASTERN HIMALAYAS

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ABSTRACT
The impact of climate change is felt on various aspects of the natural environment i.e. on freshwater resources; tundra, boreal forest, mountain and Mediterranean-type ecosystems; mangroves and salt marshes; coral reefs and the sea-ice biomes; food, fiber and forest products; low-lying areas; health; industry and eventually human society. The mountains are being affected specifically due to climate change at a rapid rate. These impacts are being felt across all the mountainous regions of the world including the Himalayas, where water resources, flora and fauna and the dependent population are directly affected. Glacial lakes have been an integral part of mountain landscape which could be of bedrock-dammed, moraine-dammed, ice-dammed or landslide-dammed origin. These lakes are impounded unstably and if their damming fails then a large quantity of stored freshwater is released in the form of flash floods referred to as Glacial Lake Outburst Flood (GLOF). The landslide-dammed lakes are common in the Himalayan region. In the Indian state of Sikkim, the Himalayan glaciers are receding considerably at variable rates due to which there has been a concentration of a large number of glacial lakes in this region and there is an increasing threat in case of an outburst of any such glacial lake.

Keywords: *Climate Change, GLOF, Glaciers, Himalayas, Sikkim*

INTRODUCTION
The atmospheric composition has been altered globally significantly since industrialization and has paved the way for climate change of unprecedented character. In a Special Report on the Ocean and Cryosphere in a Changing Climate, IPCC observes that there has been lessening of snow cover, a huge loss of ice-sheets and glaciers over the decades globally (IPCC, 2019). Mountains and their adjacent valleys which occupy 24% of the Earth's surface are sensitive to climate change as they have a considerable effect on the water resources of the world (Wester et al. 2019). An estimated 40% of the world population derives resources from the mountains either directly or indirectly. The High Mountains of Asia have the largest glacial reserve other than the polar regions (Brun, 2017). The Himalayas, known as the water tower of the world **(**Bajracharya *et al.*, 2008) provide water to billions of Asians. The population of the Hindu Kush Himalaya region in India was 76.98 million in the year 2011 which increased to 86.27 million during 2017 and this population is estimated to reach 110.44 by 2030 (Wester *et al.,* 2019). In the deglaciated areas, glacial lakes have become an integral part of the mountain landscape and now the number of such lakes has grown. Also, the existing lakes are gaining size due to further melting of the glaciers.
Several studies suggest that the mountains are being affected due to climate change at a rapid rate. The observed incidents have substantially increased from 1930 onwards the world over (Harrison, 2018). The impacts of gradually rising temperatures are being felt across all the mountainous regions of the world including the Himalayas, where water resources, flora and fauna and the dependent population are directly affected and are a major indicator as well. All the more it is projected that most of the glacial ice cover might vanish by the end of the century (Kraaijenbrink, 2017). A decline in local agricultural yields

in the high Himalayan mountainous regions has been witnessed due to receding glaciers and reducing snow cover (Hock, 2019).

Concept

"Glacial lake outburst flood" (GLOF) is a phrase used to describe a sudden release of a significant amount of water retained in a glacial lake, irrespective of the cause. GLOFs are characterized by extreme peak discharges, often several times over the maximum discharges of hydrometeorological induced floods, with an exceptional erosion/ transport potential; therefore, they can turn into flow-type movements" (Emmer, 2017). In the natural depression of the region, the glacial ice or moraines impound water and glacial lakes are formed, such lakes have been responsible for re-shaping the geography of many regions. But these lakes are impounded unstably and if their damming fails then a large quantity of stored freshwater is released in the form of flash floods i.e. GLOF and cause destruction of valuable natural resources and the high-cost infrastructural investment in the mountains. Such events originating in the Hindu Kush-Himalayan region have trans-boundary impacts (Dema, 2019); hence, the potential GLOFs need to be monitored properly to reduce the vulnerability in the watersheds of the Himalayan rivers and streams.

Table 1: Rate of Retreating Glaciers in the Himalayan Region

Glacier	Retreating Rate	Source
Siachen and Pindari Glaciers	31.5m and 23.5m per year respectively	Vohra, 1981
Gara, Gor Garang, Shaune Garang, NagpoTokpo Glaciers of Satluj River Basin	4.22 - 6.8 m/year	
Bara Shigri, Chhota Shigri, Miyar, Hamtah, Nagpo Tokpo, Triloknath and Sonapani Glaciers in Chenab River Basin	6.81 to 29.78 m/year	
Milam Glacier in the Kumaon Himalaya	9.1m per year from 1901 and 1997	Shukla and Siddiqui, 1999
Snout of Dokriani Bamak Glacier in the Garhwal Himalaya	586m retreat during 1962 to 1997	Dobhal *et al.*, 1999
Dokriani Bamak Glacier	20m in 1998, compared to an average retreat of 16.5m over the previous thirty-five years	Matny, 2000
Janapa Glacier	696m during 1963 -1997	Kulkarni *et al.*, 2004
Jorya Garang	425m during 1963 -1997	
Naradu Garang	550m during 1963 -1997	
Bilare Bange	90m during 1963 -1997	
Karu Garang	800 m during 1963 -1997	
Baspa Bamak	380m during 1963 -1997	
Parbati Glacier in Kullu District	178 m/year during 1962 to 2000	

Source: Adapted from Bajracharya et al., 2008

Such changes have not only been responsible for taking lives but also adversely impact the beauteousness, cultural scenario and overall well-being of the mountain dwellers (Hock, 2019). The glacial lakes could be:

- *bedrock-dammed* i.e. stable and formed of solid rocks
- *moraine-dammed* i.e. a moraine filled with water
- *ice-dammed* i.e. situated on/ underneath/ within or on the margins of glaciers.
- *landslide-dammed* i.e. when water is retained due to a barrier constructed of debris or rocks

The most prevalent type of glacial lakes is the moraine-dammed (CWC, 2019).

Causes and Status

The reasons which cause glacial lake outburst floods are driven by climate change wherein the mountain slope deposit debris rapidly in the lake through landslides, avalanches etc. or the lake region experiences heavy precipitation which can cause flooding or a sudden event of earthquake-like Lake Safuna Alta, Cordillera Blanca, Peru flooding in 1970. In Indian Himalayas, the first GLOF event was recorded in 1926 from Shyok Glacier which caused havoc in an area of about 400 km from the outburst site. (Basu, 2015). The recent occurrence of flood in the Kedarnath region in 2013 raised an alert when the Choradari Lake had breached its dams (Rafiq, 2019) and caused massive destruction. This lake was lateral moraine-dammed and had disappeared after the outburst (Nie, 2018). The damage gets accelerated as the fast-moving water starts putting huge boulders into motion (Cook, 2018). Table - 1 shows a compilation of the retreating glaciers and their rate in the Himalayan region.

The Central Water Commission monitors glacial lakes and water bodies in India and has prepared their inventory covering an area of more than 10 ha in the Himalayan region providing their nomenclature, coordinates, elevation and catchment area. It states that in India there are 448 water bodies and 60 glacier lakes (CWC, 2019). At least 20 GLOF events have been recorded in the Himalayas in the last 7 decades causing damages to agricultural land and forests and inflicting heavy loss of human lives and property (Mool et al. 2001).

The glacial lakes in the eastern part of the Himalayas were bigger and more numerous as compared to the west which is growing in number and area; and is likely to be the GLOF hazard hotspot (Padma, 2021).

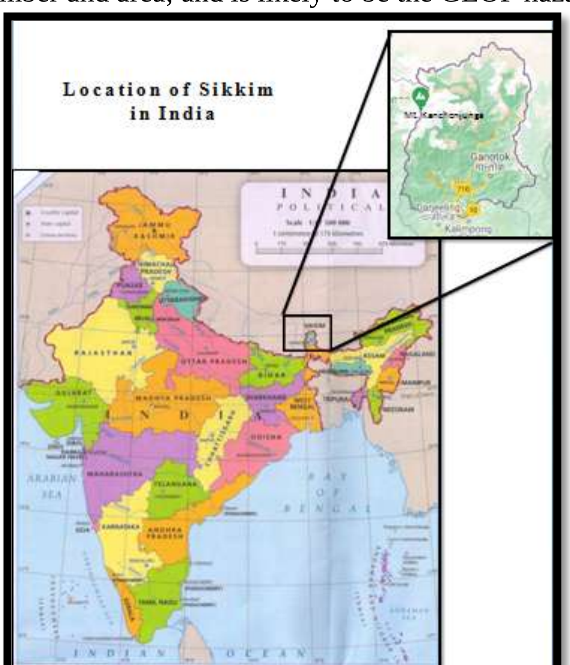

Figure 1: Location of Sikkim in India

Source *- Created by the author using an image from Google and Oxford Student Atlas for India (2018)*

Sikkim

Sikkim lies in Northeast India between 27° 00′ 46″ N to 28° 07′ 48″ N latitude and 88° 00′ 58″ E to 88° 55′ 25″ E longitude, amidst Eastern Himalayas covering 7096 sq km is the second smallest Indian state which is acclaimed for its alpine and subtropical climatic biodiversity. Furthermore, Mount Kanchenjunga which is the highest peak in India and the third-highest on Earth adds to its natural beauty. The important glaciers in the state are Zemu, Rathong and Lhonak. The status of these Glaciers has become a measuring stick of climate change (Space Applications Centre 2010).

Unfortunately, in this Indian state, the glaciers are receding considerably at variable rates due to which there has been a concentration of a large number of glacial lakes in this region. In 2017 with the help of IRS Resourcesat-2 LISS-IV data (5.8 m), high-resolution base data has been created and Aggarwal et al. 2017 identified and mapped 1,104 lakes situated above 3,500 m above sea level covering an area of 30.498 sq km. The study also found that 21 glacial lakes were potentially hazardous as they increased in the area during 1972–2015 which could be a potential threat. The Zemu glacier, Changme Khangpu glacier, East Rathong glacier, South Lhonak glacier receded at various rates over the last few decades. The debris has also increased in this area (Shukla *et al.*, 2018).

Further, Shukla et al. 2018 classified the glacial lakes at Sikkim of Zemu, Talung, East Rathong and Changme Khangpu basins into supraglacial lakes {if combined then form proglacial lakes (Maskey,2020)}, periglacial lakes in contact with glaciers, periglacial lakes away from the glaciers and other lakes to observe temporal changes from 1975 to 2017. The findings suggest that the cumulative area of the lakes increased from 25.17 sq km to 31.24 sq km. The basin wise number of glaciers too increased from 219 to 252 in the Zemu Basin, from 14 to 16 in the Talung Basin, from 38 to 39 in the East Rathong Basin and from 154 to 159 in the Changme Khangpu basin. One of the main causes behind this phenomenon was that these glacial lakes are now monsoon fed as incidents of rainfall have increased in the state because of which the lakes have gained area and volume; additionally, monsoon floods are known to be cataclysmic in the Himalayas (Veh, 2020). Avalanches too are seen as a major catalyst behind such floods (Byers, 2019). It is indeed important to study the characteristics of the factors that result in the outburst of glacial lakes rather than concentrating on the size of the lakes only (Veh, 2019). Therefore, the glacial lakes and water bodies require vigorous monitoring by studying both the status of hazard and impact it can cause downstream (Langenbrunner, 2020) to avoid any future disaster. It must also be kept in consideration that even in the distant future the glaciers will contribute water but the flow will vary regionally (Huss, 2018).

Furthermore, Sikkim falls in Zone-IV of the Indian seismic chart and earthquakes too may trigger GLOF (Basu 2015). With the rise in the number of glacial lakes in Sikkim, Eastern Himalayas the local population is immensely concerned about its future. Adaptation and mitigation techniques depending on environmental and socio-economic conditions along with the apt use of information and technology can help in responding to this changing scenario effectively. As the glaciers are remotely located (Nagai, 2017) hence, collecting precise data is difficult unless techniques such as Remote Sensing are applied.

Measures

Sikkim has experienced various flash floods in the past. Taking a lesson from that, the state now has a group of trained volunteers known as 'Apada Mitras'. The state even observes Disaster Day on 18th September to create awareness and generate a need for preparedness to prevent natural disasters. Various projects are being taken up by disaster managers and scientists in the state to prevent disasters related to the outburst from glacial lakes. One such example in the state is of installing high-density polyethene pipes to drain water off the South Lhonak glacial lake (Singh, 2018).

CONCLUSION

Climate Change is a reality and its direct and indirect impacts are being felt globally. Adaptation and formulating suitable future plans are the only way for effective survival for the humans. Melting of glaciers cannot be controlled but they can be managed. Glacial lake water, if well managed, can be beneficial to the local community as it stores freshwater naturally and add to the tourist attractions in the region. Regular monitoring, relevant research and studies and awareness programs can help the human colonies live sustainably in this area and also prosper.

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