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Glacial Lake Outburst Threats and Management: Insight from Sikkim's Flood Event

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Abstract: *Glaciers are particularly sensitive to changes in climate, and among the most visible indicators of climate warming. There have been substantial decreases in global glacier mass over the last few decades, and this decline is likely to persist through the 21st century as many glaciers is out of balance with present climate. The formation of glacial lakes can trigger positive feedbacks, whereby lakes promote further ice loss through calving and subaqueous melting, causing additional melt and retreat, and further lake expansion. These lakes can represent a substantial hazard in the form of glacial lake outburst floods (GLOFs). GLOFs can be highly destructive and can arrive with little warning, causing significant damage to property, infrastructure, and agricultural land, and resulting in extensive loss of life.*

GLOFs are among the most concerning consequences of retreating glaciers in mountain ranges across the planet, and can result in significant loss of life. Since 1990, the number and size of glacial lakes has rapidly grown globally, along with downstream population, while socio-economic vulnerability has increased. Populations in High Mountains Asia (HMA) are the most exposed to GLOFs, and more than half of the globally exposed population is found in just four countries: India, Pakistan, Peru, and China.

The objective of this study is to shed light to assess what triggered the Sikkim GLOF event, the damage caused by this event and future probability of events like the Sikkim flood. This study also discusses the Flood prone areas in India, as well as implications of implications of climate change and human activities in increasing the treats of GLOFs.

On the early hours of October 4th, 2023, the South Lhonak Lake in North Sikkim breached, causing a Glacial Lake Outburst Flood (GLOF). Lying approximately 60 kilometers downstream of the lake, in Chungthang town of Mangan district, was the 1,200 MW Teesta III dam, the biggest hydropower project in Sikkim. The dam was decimated by the GLOF. This flood also unleashed devastation on downstream areas and communities. GLOFs can lead to catastrophic flooding downstream, capable of releasing millions of cubic meters of water within a short timeframe. Peak flows during GLOFs have been documented as reaching as high as 15,000 cubic meters per second, according to the National Disaster Management Authority.

Key Words: *Glaciers, Global Warming, Glacial bleaching, Glacial Lake outburst floods, Sikkim-flood, Catastrophic, Mitigation efforts.*

1. INTRODUCTION :

Flooding is a common natural hazard in many areas of the world, and its frequency and magnitude are expected to go up with climate warming. While previous studies had indicated that flood frequency is non-stationary, several water management designs have assumed that flood occurrence or magnitude is stationary based on patterns observed in the past. Hence, it becomes vial to analyze the magnitude and frequency of flooding to adequate adaptation and mitigation strategies.

The rugged Himalayan landscape, characterized by its steep mountains, is especially prone to GLOFs (Glacial Lake Outburst Floods). The ongoing effects of climate change, marked by increasing global temperatures, have accelerated the process of glacier melting in the Sikkim Himalayas. Now, the region has over 300 glacial lakes, with ten identified as at risk of experiencing outburst floods. GLOFs can be triggered by various factors, such as earthquakes, exceptionally heavy rainfall, and ice avalanches.

Located approximately 5,200 meters above sea level in northern Sikkim, South Lhonak Lake has been a major cause for concern among scientists due to its expansion, possibly attributed to ice melting at its source. Notably, seismic events like the magnitude 6.9 earthquake in 2011 heightened the risk of GLOFs in the area.

In response, the Sikkim State Disaster Management Authority and other stakeholders initiated a crucial plan in 2016 to reduce the excess water in South Lhonak Lake. Renowned innovator Sonam Wangchuk spearheaded this endeavor, utilizing High Density Polyethylene (HDPE) pipes to drain water from the lake. This initiative successfully decreased the lake's water volume by about 50%, mitigating the risk to some extent.

However, a recent tragic incident in 2023 is believed to have been triggered by an avalanche originating from the ice-covered feature surrounding the lake, highlighting the ongoing challenges despite such mitigation efforts. The casualties rose steadily in the aftermath of the flash flood resulting from the GLOF incident at South Lhonak Lake in the North Sikkim District of Sikkim State. After this occurrence, there was a sudden increase in the Teesta River's water flow, causing the destruction of multiple bridges, substantial damage to sections of NH-10 and the Chungthang Dam, and affecting various small towns situated in the upper regions of the Teesta River valley.

2. LITERATURE REVIEW :

Dubey (2020) looks at the possible impacts of GLOFs on settlements and infrastructure from 329 glacial lakes and classified them according to hazard-risks. Sikkim had the highest count of lakes categorized as very high hazard (20), trailed by Ladakh and Jammu and Kashmir, both union territories with four such lakes each. Himachal Pradesh and Arunachal Pradesh had two lakes each falling into the very high hazard category, while Uttarakhand was found devoid of such lakes as per his study. The term "hazard" in this context pertains to the potential for a lake to breach. His study puts emphasis on the significance of considering the number of impacting lakes, their size, and worst-case scenarios when planning a hydropower plant. It highlights the importance of assessing how these factors might affect the power plant's placement and operational safety.

The Ministry of Environment, Forests, and Climate Change has mandated that large hydropower projects must undergo a "dam break" or "dam fail" analysis to secure environmental clearance. According to a paper by the National Institute of Public Finance and Policy (NIPFP) (2021), while this analysis is obligatory, the level of compliance across projects remains unclear. The study examined the Environmental Impact Assessments of six major hydro projects and discovered inconsistencies: "There is a lack of uniformity in the parameters and procedures utilized for dam failure analysis. In some instances, the dam failure analysis is absent from the publicly available documents." The Environmental Impact Assessment encompasses the Environmental Management Plan (EMP).

Additionally, the NIPFP paper highlights that the current design standards for dams are primarily based on their heights and storage capacities and do not adequately consider the risks posed by the dam. Despite the mandatory nature of dam failure analyses, the paper underscores the absence of a requirement for conducting a consequence analysis. This refers to the quantification of potential loss of lives, livelihoods, and property damage in the event of a dam failure.

Prakash Tripathi (2015)says that floods in India have emerged as a major catastrophe claiming the lives of numerous individuals in recent years. The frequency and severity of these incidents have escalated, significantly impacting both lives and the economy. While the Government of India has implemented various initiatives to mitigate flood and disaster-related damages, there remains a substantial journey ahead. Leveraging advancements in science, technology, telecommunications, and media for early warning systems and pre-disaster preparedness measures could significantly aid in reducing the devastating impact of such events.

3. FLOOD PRONE AREAS IN INDIA :

The Indian subcontinent possesses a distinct geographical layout that renders various parts of the nation susceptible to flooding. In the northern region, the snow-covered Himalayas harbor some of the world's largest glaciers, serving as the origins of numerous perennial rivers. These rivers traverse extensive plains, densely inhabited by millions of Indians. Unfortunately, these vast plains are highly vulnerable to flooding, particularly during the monsoon season when heavy rainfall causes the rivers to swell. According to the National Institute of Disaster Management (NIDM), India experiences an average annual rainfall of 1150 mm, varying significantly across the country.

Regions along the western coast, Western Ghats, Khasi hills, and much of the Brahmaputra valley receive rainfall exceeding 2500 mm annually. Most river floods occur during the monsoon period and are typically linked to tropical storms, active monsoons, or breaks in monsoon conditions. Apart from river floods, heavy rainfall, cloud bursts, glacial lake outbursts, and tsunamis contribute to flooding.

The Vulnerability Atlas of flood zones in India, issued by the Central Water Commission, identifies the Indo-Ganga-Brahmaputra plain and the coastal areas in the Eastern and Western regions as the primary flood-prone zones.

River floods result from the convergence of water from various tributaries, carrying substantial silt and sand deposits that reduce the river's flow pace, causing horizontal expansion and submerging nearby habitats.

In several flood-prone states, land depression and low-pressure areas are the two significant synoptic systems responsible for floods. According to NIDM, in Bihar, 100% of floods and 82% in Uttar Pradesh are caused by land depression and well-marked low pressure, while in West Bengal, cyclonic circulation is the primary cause. Punjab, Gujarat, Rajasthan, and Jammu & Kashmir face frequent flooding due to low-pressure areas. Floods in Orissa and Andhra Pradesh are attributed to monsoon depressions.

In recent times, metropolitan cities are grappling with recurrent flood episodes, primarily due to mismanaged drainage and sewer systems clogged by irresponsible waste disposal and inadequate maintenance by relevant authorities. Coastal flooding predominantly arises from cyclones and tsunamis.

Rastriya Barh Aayog (1980) highlighted that 12% of India's land comprises flooded areas, encompassing approximately 40 million hectares. This figure has escalated to 49.815 million hectares according to the Central Water Commission's database, based on flood damage data reported by states from 1953 to 2010. On average, floods affect 7.2 million hectares of land and 3.19 million people annually.

4. GLACIER LAKE OUTBURST: AN OVERVIEW :

A GLOF, or Glacial Lake Outburst Flood, refers to a sudden and potentially disastrous deluge that happens when water stored behind a glacier or a moraine— a natural accumulation of ice, sand, pebbles, and debris— is swiftly released. These floods occur due to the buildup of water in glacial lakes formed by melting ice, held back by vulnerable moraine dams. Unlike robust earthen dams, these moraine barriers can collapse suddenly, resulting in the rapid discharge of substantial water volumes within minutes to days, causing severe flooding downstream.

Located in North Sikkim, the South Lhonak glacier is among the fastest retreating glaciers. The glacier receded almost 2 km in 46 years from 1962 to 2008. It further retreated by about ~400 m from 2008 to the year of 2019. There are approximately 7,500 glaciers in the Himalayas, and GLOFs has been linked with several major disasters over the years.

As per a report in journal Nature, the 2013 Kedarnath outburst in Uttarakhand, the 1981 Kinnaur valley floods in Himachal Pradesh and the 1926 Jammu and Kashmir deluge are examples of GLOF associated disasters. Sikkim is known to have more glaciers than any other Himalayan state in India, and climatologists have warned over the years that these glaciers can be responsible for lake outbursts.

A massive flood was caused from a glacier-lake outburst in Sikkim in the early hours of October 4th 2023. Voluminous flow from this outburst destroyed the Chungthang dam, which was vital to the Teesta 3 hydropower project. The flood also rendered multiple hydropower projects along the river dysfunctional.

5. EARLY WARNINGS :

The Information and Public Relations Department of Sikkim issued a press release on May 13th, 2023 about the risks posed in the event of Glacial Lake Outburst Floods at the South Lhonak and Shako Cho glacial lakes. The press release quoted DG Shrestha, Director, Sikkim Department of Science and Technology, who had highlighted the increasing size of the South Lhonak Lake and urgent need for an Early Warning System for these glacial lakes in Sikkim.

The Sikkim State Disaster Management Authority had proposed an expert committee for studying and evaluating the 10 vulnerable glacial lakes in Sikkim, in a presentation made at a National Disaster Management Authority conference.

Hence, both the state and national authorities were aware that the South Lhonak glacial lake is highly vulnerable to a GLOF event as the 60 metre high, 1200 MW Teesta 3 Hydroelectric Project is just 50 km downstream as the crow flies. However, the flash floods triggered on the night of October 3-4 2023 showed that there was no early warning issued in time to downstream communities.

CAG of India’s ‘Performance Audit on Schemes for Flood Control and Flood Forecasting’ (Report No 10 of 2017) shows how much of Sikkim is flood prone. With the increase in the development activities in the city in the last two decades, the GLOF-triggered flash floods are a very real threat.

6. IMPLICATIONS OF CLIMATE CHANGE AND HUMAN ACTIVITIES :

Climate change has emerged as a pivotal factor influencing the evolving geo-environment of the Himalayas. Scientists continually caution that the Himalayan region is experiencing a faster rate of warming compared to adjacent lowland areas. This accelerated warming has spurred numerous geomorphic processes, notably the rapid melting of glaciers. Consequently, this accelerated melting has contributed to the formation of several potentially hazardous Glacial

Lakes in recent times. The rapid changes in these geomorphic processes were unforeseen by dam planners and engineers over two decades ago, when many dams in Sikkim were originally planned.

An official from Teesta-III mentioned, "Mega projects require 42 years of water data for National Seismic Designing Authority's recommendation and final approval by the Central Electricity Authority (CEA). Based on records of a 680 cumecs (discharge) flood in Chungthang in 1973, the Teesta III dam was designed to withstand 7000 cumecs." However, the Sikkim-Darjeeling Himalayan region lacked extensive long-term data during the early 2000s when dam planning and design took place. This absence of comprehensive data prompts critics of hydropower dams in the Himalayan region, including Sikkim, to question the technical, environmental, and human procedures followed by their proponents.

Regarding the delayed opening of spillways, timely action could have mitigated the impact of the flood if the dam gates of Teesta-III had been opened promptly. Unfortunately, the information reached relevant authorities in Chungthang after the flood had already struck, compelling residents to flee for their safety instead of opening the gates.

The entire Himalayan region is a delicate ecological zone that appears robust but is inherently vulnerable to various geo-environmental and geomorphic processes influenced by climate, geology, flora, fauna, and water resources. These processes often lead to natural hazards that escalate into disasters due to the region's conditions and insufficient disaster preparedness mechanisms. Additionally, accelerated natural processes in recent times result from unscientific and unsustainable human activities, including the construction of large-scale hydropower dams.

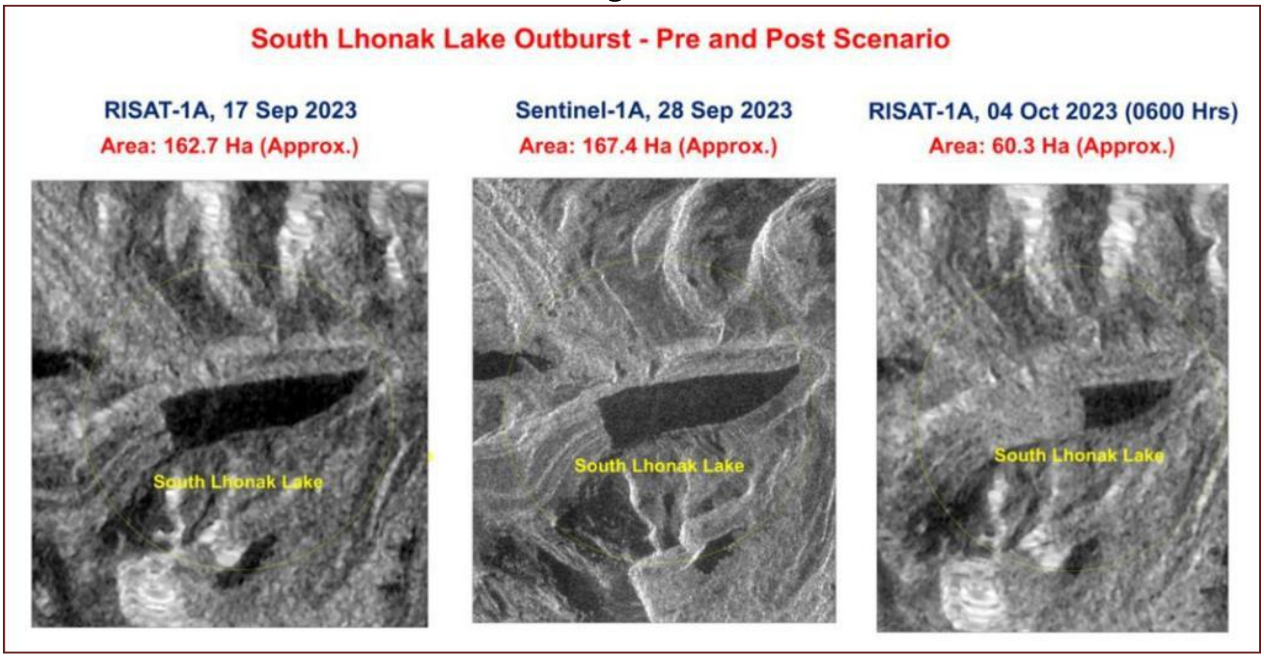
Given Sikkim's high concentration of hydropower projects, it is crucial to develop a comprehensive regional hydropower policy tailored to its unique environment, ecological setup, and geography. A well-informed hydropower policy must account for the region's geological and geomorphic specifics. Prioritizing the integration of Disaster Risk Reduction (DRR) and climate change within the hydropower policy framework becomes imperative in safeguarding the region's interests.

7. WHAT TRIGGERED THE SIKKIM GLOF EVENT?

Global warming has heightened the severity and regularity of extreme weather patterns, such as Glacial Lake Outburst Floods (GLOFs) in the Himalayas. Although GLOFs are not new occurrences in this region, their frequency has notably increased over the last few decades. The number of potentially hazardous glacial lakes has also risen across the Himalayas, including in the Sikkim Himalaya.

GLOFs primarily result from the melting of glaciers. The rapid retreat of glaciers in recent years has caused several glacial lakes to expand. As glaciers recede, they create voids that these lakes occupy, filling the depressions that were once occupied by glacial ice. These natural dams formed by the lakes are inherently weak and unstable, undergoing continual changes due to slope failures, slumping, and other factors, posing a significant risk of triggering GLOF

Fig.1.1



Source: Satellite image-based studies of South Lhonak Lake from ISRO

There are still uncertainties associated with the prime cause of Sikkim GLOF event. Satellite images from the National Remote Sensing Centre, Indian Space Research Organization suggest that 105 hectares of the glacier-fed lake had been drained out. This was based on the comparing images taken on September 28 2023, when the lake spanned 167 ha and on October 4th, the night of the disaster, when it shrunk to 62 ha. It was 162 ha on September 17th. Calculating the volume of water in the lake is a challenge without visiting the place as satellite images do not reveal the depth of the lake. Water monitoring apparatus maintained by the Central Water Commission (CWC), however, reports that water levels surged nearly 60 feet above the maximum levels at Sangalang at 1:30 pm and gushed at nearly 55 kmph. This is essentially about thousands of cubic metres of water in a short time and being midnight, giving very little lead time for people downstream to react.

As per the National Disaster Management Agency report, the prime reason for the sudden surge was likely to be combination of excess rainfall and a GLOF event. The lake is at a height of 5,200 meters with a towering ice-capped feature at about 6,800 meters to the north of and near the lake. There is also speculation that heavy rainfall might have tipped the moraine to collapse and triggedthe flood but there is no evidence of such heavy rain as per meteorological records. According to Director General, India Meteorological Department (IMD), there was heavy rain in south Sikkim but nothing remarkable in the northern region. But as there is no monitoring of rainfall at such a height, no absolute statement can be made. There has also been suggestions that that a series of earthquakes in Nepal on October 3rd 2023, in the afternoon,) might have played a role. The tremors from this earthquake jolted several in the Delhi National Capital Region. There were two tremors in the afternoon and aftershocks until at about 9 pm on the 3rd. The distance (until Lhonak lake) is approximately 700 km and hence it is possible theoretically that this could be a trigger. But in absence of a deeper study, this is simply a speculation. The inaccessibility of the terrain around the Sikkim floodmakes ground observations that provide conclusive proof difficult.

8. WHAT WAS THE RESULTING DAMAGE OF THE SIKKIM FLOOD?

More than 25 people have been confirmed dead, and many more are missing from a massive flood that resulted from a glacier-lake outburst in Sikkim in the early hours of October 4th. According to a preliminary assessment report by Sphere India, more than 88,000 people have been directly affected by this event. 33 bridges, two government buildings, and 16 roads and highways had been damaged due to it.

Satellite imagery obtained from NRSC (ISRO) at 0600 hrs on October 4, 2023, depicted that more than half of the lake had drained out. According to CWC's monitoring stations, the initial surge of water measured 19 meters above the maximum water level at Sangkalang by 0130 hrs and 4 meters above the maximum water level at Melli by 0400 hrs. Upon receiving this information, alerts were promptly issued to downstream settlements, and Relief and Rescue Operations were launched by NDRF, SDRF, ITBP, Army, and the civil administration of Sikkim. However, ongoing snowfall in higher regions and precipitation with clouds in lower regions are impeding the deployment of helicopters and hindering relief operations.

The destruction of the Chungthang dam was the most visible consequence of the flooding. Even though not a storage dam, it water to power the Teesta 3 hydropower project. As the executive chairman of Sikkim Urja, which runs the project, the dam was washed away in 10 minutes. As per the senior officials in the CWC, the dam was considerably damaged, and the quantity of water and silt present in it made it difficult to estimate the extent of damage.

Due to the flood, all bridges downstream to the Teesta-V hydropower station were submerged or washed out, thereby disrupting communication. The floodwater overtopped the dam of the Teesta V power station [510 MW], and all connecting roads to the project sites along with parts of the residential colony got severely damaged. One NHPC employee at the Teesta V power station even lost his life.

Activities on the under-construction Teesta VI (500 MW) of the NHPC got disrupted as water entered into the powerhouse and transformer cavern. Dams and hydropower projects in downstream West Bengal were not affected to a considerable extent but were kept shut due to the heavy siltation that resulted from the floodwaters.

The State government had set up 26 relief camps in the four affected districts as per the Sikkim State Disaster Management Authority (SSDMA) and at least 1,025 people took shelter in the eight relief camps in Gangtok district. The flood destroyed 11 bridges in the state. Eight bridges got washed away in the Mangan district alone. Two bridges were destroyed in Namchi and one in Gangtok. Sewage lines, water pipelines and about 277 houses were destroyed in the four most affected districts, which included Namchi, Pakyong, Gangtok and Mangan**.**

9. FUTURE PROBABILITY OF EVENTS LIKE THE SIKKIM FLOOD :

Several studies have over the years warned of the risk from GLOF events from the Himalayas. Both the severity and frequency of such events are likely to go up exponentially in the future. The Himalayan ecosystem is very fragile, and any disruption in managing its resources is likely to have problematic outcome for the people of the region. Rising temperature levels is not only paving way for a wetter future and contributing to climate change led extreme events, but is also disturbing the fragility of the Himalayan ecosystem through hydropower and other dams. GLOF essentially is an outcome of the warming of the locality, and has been a major risk for the region. After it is formed, one may never know what triggers its outburst. Sikkim is an example of such a situation.

While the Teesta River is a source of hydropower generation for several power projects, the risk of GLOF like events requires greater care in planning and executing dam and other infrastructure projects, which account for the huge amount of water that can potentially gush through the mountains.Early warning systems are implementable, requires a coordinated approach such as multiple agencies promptly sharing satellite images (that are trained towards the Himalayas) and a network of sensors to provide adequate warning. As opposed to an earthquake, that is relatively sudden, GLOF events can be anticipated as it is possible to monitor changes in the size of lakes. But it does require greater coordination.

10. MANAGING GLOF RISKS :

Highlighting the concerning trend of Himalayan glacier retreat, the National Disaster Management Authority collaborated with the Swiss Agency for Development and Cooperation to issue guidelines addressing the management of GLOFs (Glacial Lake Outburst Floods). These guidelines recommended the establishment of a task committee responsible for drafting specific regulations aimed at mitigating the heightened risk of future GLOF incidents. They further suggested the creation of unified legislation to regulate construction activities, integrating the existing legislative framework and incorporating proposed recommendations.

To bolster resilience against GLOF threats, essential elements include access to data and information, capacity-building, the implementation of early warning systems, and the development of well-designed infrastructure. Accomplishing this requires substantial funding from both public and private sources, innovative financial mechanisms, comprehensive regional coordination, and the active involvement of governments.

The challenges posed by GLOFs transcend borders, spanning subnational jurisdictions and international boundaries. This underscores the necessity of establishing effective communication platforms to facilitate cross-border sharing of data, information, knowledge, and experiences. Similar to other developing regions, South Asian nations are striving to achieve mitigation targets independently while relying on financial assistance from more developed nations to bolster mitigation, adaptation efforts, and fulfill their commitments outlined in the Paris Agreement.

REFERENCES:

Journal Papers:

1. Devendra Damle (2021), Dam Safety in India, NIPFP Working Paper Series
2. Kraaijenbrink, P. D. A., Bierkens, M. F. P., Lutz, A. F. & Immerzeel, W. W. Impact of a global temperature rise of 1.5 °C on Asia’s glaciers. Nature 549, 257–260 (2017)
3. Milly PCD, Betancourt J, Falkenmark M, Hirsch RM, Kundzewicz ZW, Lettenmaier DP, Stouffer RJ (2008) Climate change - Stationarity is dead: whither water management? Science 319:573–574
4. Roe, G. H., Baker, M. B. & Herla, F. Centennial glacier retreat as categorical evidence of regional climate change. Nat. Geosci. 10, 95–99 (2017)
5. Saket Dubey and Manish Kumar Goyal (2020), (Glacial Lake Outburst Flood (GLOF) Hazard, Downstream Impact, and Risk over the Indian Himalayas
6. Tripathi, Prakash. (2015). Flood Disaster in India: An Analysis of trend and Preparedness. Interdisciplinary Journal of Contemporary Research.
7. Villarini G, Serinaldi F, Smith JA, and Krajewski WF. (2009). On the stationarity of annual flood peaks in the continental United States during the 20th century. Water Resource 45, W08417, https://doi.org/10.1029/2008WR007645
8. Wolfgang Schwanghart et al 2016 Environ. Res. Lett. 11 074005 Environ. Res. Lett. 11 074005
9. Wouters, B., Gardner, A. S. &Moholdt, G. Global glacier mass loss during the GRACE satellite mission (2002–2016). Front. Earth Sci. 7, (2019)

Web References:

- https://cag.gov.in/en/audit-report/details/31347
- https://ndma.gov.in/sites/default/files/PDF/PR-Flash-Flood-Sikkim-South%20Lhonak.pdf
- https://thewire.in/environment/sikkim-disaster-vimal-khawas-interview-himalaya
- https://thewire.in/environment/sikkim-glof-triggered-flood-in-teesta-because-warnings-remained-neglected
- https://www.acaps.org/fileadmin/Data_Product/Main_media/20231012_ACAPS_Briefing_note_India_floods_in_Sikkim_state.pdf
- https://www.drishtiias.com/daily-updates/daily-news-analysis/glacial-lake-outburst-flood-in-sikkim
- https://www.isro.gov.in/Satellite_studies_South_Lhonak_Lake.html
- https://www.thehindu.com/sci-tech/energy-and-environment/what-caused-the-flood-in-sikkim-explained/article67397335.ece