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ESTIMATION OF GLACIAL LAKE OUTBURST FLOOD (GLOF) FOR PLANNING AND DESIGN OF HYDROELECTRIC PROJECTS IN THE HIMALAYAS

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1. IMPORTANCE OF HYDROELECTRIC PROJECTS IN INDIA

India is blessed with immense hydroelectric potential and ranks 5th in exploitable hydro-potential in the global scenario. As per assessment made by Central Electricity Authority (CEA), India is endowed with economically exploitable hydropower potential to the tune of 1,48,700 MW of installed capacity. As of March 31, 2020, India's installed utility-scale hydroelectric capacity was 46,000 MW, about 12.3% of its total utility power generation capacity. Considering the global warming issues due to pollution from thermal power plants, hydroelectric energy and solar energy shall be a better alternative to ensure India's energy security. Many hydroelectric projects are proposed in those parts of the Himalayas in India, where the glacial lakes are also present in the project catchment.

2. INTRODUCTION OF GLOF

In the Himalayan region, almost all major rivers originate from glaciers. Glacial melt and snowmelt are the essential component of runoff in these rivers. Glacial melt and snowmelt ensure the perenniality of water into these rivers. Further, due to steep gradient availability, the Himalayan region also offers good natural sites for hydropower development, which is clean and green energy required for the country's development. Due to essential developmental activities in the upper reaches of the Himalayas, mainly due to increased vehicular movements and settlements, global warming rise in temperature is occurring in these regions, resulting in the melting of glaciers in their lower ablation areas. The glaciers are a moving mass of ice. When the glaciers move, they also erode the valley material beneath. This valley material gets accumulated at the glacier's snout, forming a natural moraine dam over some time. Due to the melting of glaciers and rainfall, the water gets accumulated behind such moraine dams forming a moraine-dammed glacial lake. The abrupt breaching of a moraine dam of a glacier lake releases a flash flood of the significant peak known as Glacial Lake Outburst Flood (GLOF).

3. SIGNIFICANCE OF GLOF STUDY

To meet the rising energy requirements of the country and reduce the emission of Green House Gases from thermal power plants, countries like India, Nepal, Bhutan have naturally gifted Himalayan terrain having immense potential for hydropower development in the form of green energy. India has also pledged clean energy in the Conference of the Parties (COP 26) to the UN Framework Convention on Climate Change (UNFCCC), which aims to reduce the global carbon footprint. The two most critical parameters for efficient hydropower development are the availability of perennial water and high hydraulic head. If a sufficient hydraulic head is naturally available with a minimum length of tunnelling activities, then a significant amount of energy can be generated with a small quantity of water. It also significantly increases the economic viability of the projects. Because of the above reasons, several new hydroelectric projects are proposed in the Himalayas. India has about 70,000 MW of hydroelectric potential in the North Eastern Himalayas alone, out of which about 65000 MW of hydroelectric potential remains untapped. Apart from the North-eastern Himalayas, the hydroelectric potential in the Chenab basin and other river basins of Himachal Pradesh, Uttarakhand, J&K, and Ladakh regions, remain untapped. The snow-fed catchment area of the rivers in these regions has vast glaciers and many associated glacial lakes. The moraine dams are formed naturally, so they have high porosity, and hence the glacial lakes formed behind the moraine dams pose a threat of flash floods in the downstream river valley. The failure of moraine dams due to piping and overtopping is frequent.

The Indian Himalayan region is also facing the adverse impacts of climate change, resulting in the melting of glaciers at a much faster pace than before. It also increases the size of glacier lakes thus formed. The seismic activities, snow avalanches, falling of ice and boulders into the lakes, etc., make the glacial lakes vulnerable to breaches, resulting in potential disastrous flash floods in the downstream area. To ensure the hydraulic safety of river valley projects like hydroelectric projects, bridges, etc., it is essential to estimate GLOF apart from the requisite design flood for these structures. GLOF is also essential to ensure the safety of the people residing in the downstream areas from such flash floods.

4. RECENT GLOF INCIDENTS IN INDIA

Flashflood in Parechu, Spiti, and Sutlej Rivers occurred in 2005 due to the breaching of Parechu Glacial lake in China. Fortunately, NDMA and CWC already had the GLOF simulation results consisting of simulated flood peaks and travel time at different locations along the reach of the above rivers. Hence, casualties of people near downstream river reach and economic losses to HEP projects such as Nathpa Jhakri could be avoided. However, the high velocity of the above flash flood destroyed several bridges along the above river reaches.

The Chorabari Glacial lake outburst during June 2013 created a flash flood peak of about 1200 cumec, which passed through a supercritical velocity of more than 11 m/s resulting in the death of more than 5000 pilgrims at the sacred shrine of Kedarnath in Uttarakhand and Gaurikund area. The GLOF also resulted in considerable losses to Phata Buyong hydroelectric project (76 MW) and Singoli Bhatwari (99 MW), located on the Mandakini River. Due to GLOF, the entire pondage of the above projects got filled with sediments.

5. TYPES OF GLACIAL LAKES

The glacial lakes are classified into Erosion, Valley trough, Cirque, Blocked, Moraine Dammed (Lateral Moraine and End Moraine Dammed lakes), and Supraglacial lakes.

(i) Erosion lakes

Glacial Erosion lakes are formed in a depression left after glacier retreat. They may be Cirque-type or trough Valley-type lakes and are generally considered stable lakes (Fig-1 &2). These Erosion lakes might be isolated and far from the present glaciated area. These glacial lakes occupy the lowlands or emptying cirques eroded by ancient glaciers. These lakes could be dangerous if they are near potential snow avalanche sites.

Fig. 1 : Trough Valley Glacial lake (Changu Lake Sikkim) Source-Sikkim tourism.

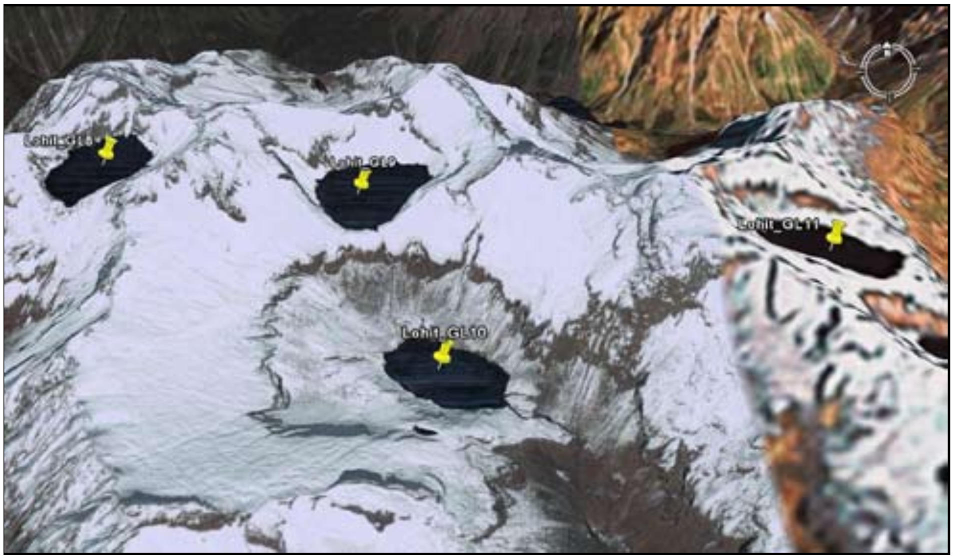

Fig. 2 : Cirque lakes in the Lohit basin

(ii) Supraglacial lakes

Supraglacial lakes develop over the surface of a glacier (Fig-3). These lakes may develop anywhere on the glacier, and the lake's surface area is usually less than half the diameter of the Valley glacier. Shifting, merging, and draining the lakes are the characteristics of the Supraglacial lakes. The merging of lakes results in expanding the lake area and storing a massive volume of water with high potential energy. The tendency of a glacial lake towards merging and expanding indicates the danger level of the GLOF. Over time, the supraglacial lakes, formed on the glacier's surface, join and take the shape of an end moraine dam glacial lake.

Fig. 3 : Supraglacial lakes formed on Thorthormi glacier, Bhutan

(iii) Moraine Dammed lakes

The glaciers are a moving mass of ice, and as it traverses downstream, it erodes the bed material. (Fig-4). The glacier's snout starts to melt, and it causes a lake on the upstream side. The eroded moraine gets gradually accumulated to form a moraine-dammed glacial lake. It is dammed by Lateral Moraine and End Moraines.

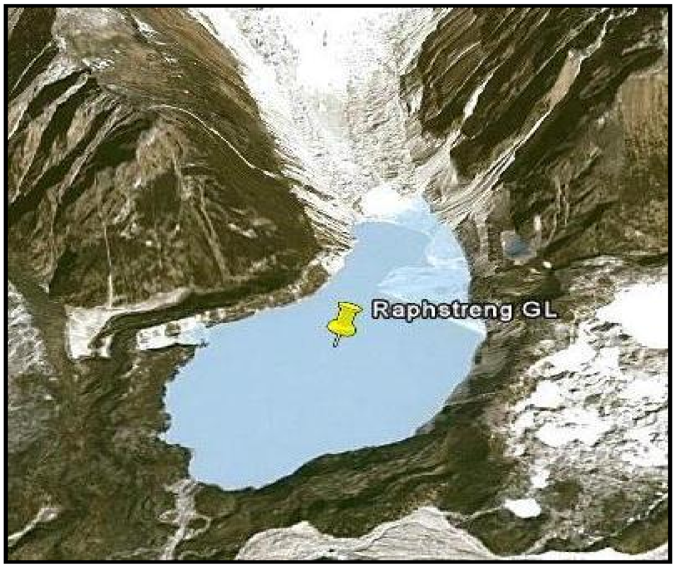

Fig. 4 : Moraine dammed Lake Raphstreng Tso, Bhutan, in contact with the glacier snout

Many supraglacial ponds may slowly grow to create an enormous moraine-dammed lake. These lakes are formed not only due to snowmelt but also from the rainfall contribution from its catchment. With the increase in temperatures and the associated melting of the glacier, the lake widens and deepens to form a substantial glacial lake with bedrock and moraines.

If one follows the life span of an individual glacier, it is found that the Moraine Dammed glacial lakes build up and disappear with a lapse of time. The moraine-dammed lakes disappear once they are destroyed or when debris fills the lakes, or the mother glacier advances again to lower altitudes beyond the moraine-dam position. Such glacial lakes are essentially ephemeral and are not stable from the point of view of the life of glaciers. Generally, moraine-dammed lakes pose a threat in the basin.

(iv) Blocking lakes

Blocking lakes are formed through glaciers and other factors, including the main glacier blocking the branch valley, the glacier branch blocking the central valley, and the lakes through snow avalanche, collapse, and debris flow blockade. (Fig. 5)

Fig. 5: Blocking lake (Satopanth Tal)

(v) Ice-dammed lakes

An Ice-dammed lake is produced on the side(s) of a glacier when an advancing glacier happens to intercept a tributary/ tributaries pouring into the central glacier valley. As such, an ice core-dammed lake is usually tiny in size and does not come into contact with the glacier ice. This type of lake is less susceptible to GLOF than a moraine-dammed lake. A glacial lake is formed and maintained only up to a particular stage of glacier fluctuation (Fig. 6).

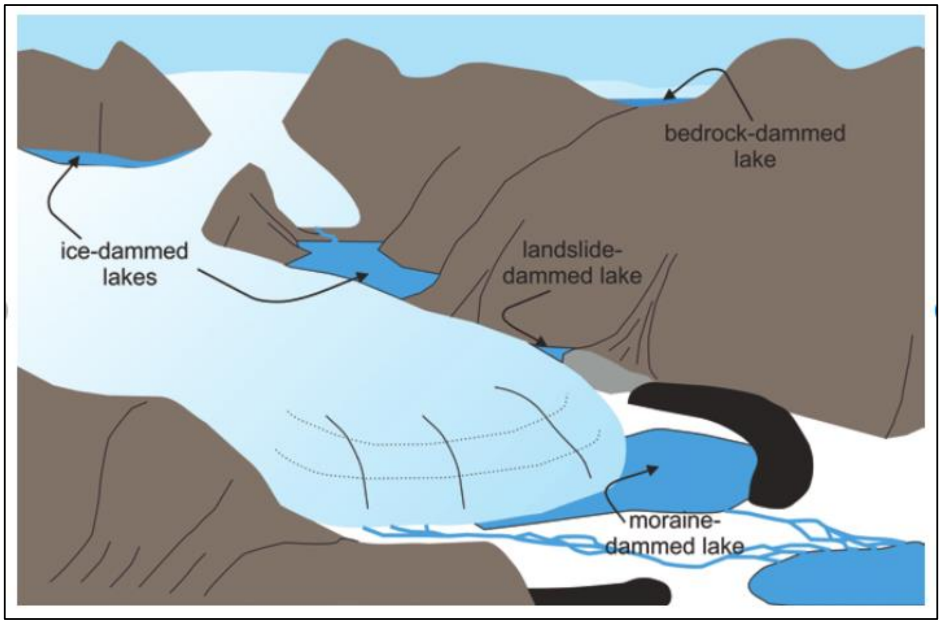

Fig. 6 : Ice dammed Lake (Source-Wikipedia)

6. LITERATURE REVIEW

For the present study, the following literature has been reviewed:

- Inventory of Glaciers, Glacial Lakes and Glacial lake outburst foods Monitoring and early warning system in Hindu-Kush Himalayan Region Bhutan prepared by ICIMOD under UNEP
- Remote sensing-based assessment of hazards from Glacial lake outbursts: a case study in Swiss Alps-Christian Huggel, Andreas Kaab, Wilfred Haeberli, Philippe Teysseire, and Frank Paul
- Approach paper on a combination of GLOF with Applicable Design Flood-N.N. Rai, Central Water Commission
- Glacial Lake Outburst Flood Risk in the Poiqu/Bhote Koshi/Sun Koshi River Basin in the Central Himalayas; Author(s): Narendra Raj Khanal, Jin-Ming Hu, and Pradeep Mool; Mountain Research and Development.
- Glacial lake atlas of Ganga River Basin prepared under National Hydrology Project, May 2021

7. METHODOLOGY TO ANALYSE GLOF

For estimating the Glacial Lake Outburst flood at the HE Project diversion site following methodology can be adopted:

- The catchment area at the project location should be delineated by GIS processing of appropriate DEM. Inventory of glacial lakes in the catchment area of the project should be prepared using the latest LANDSAT, RESOURCESAT, and other available satellite imageries, as well as Google Earth Pro.
- Based on the water spread area of the lakes, its proximity with associated mother glaciers, topographic features around the lakes and glaciers, etc., the potential glacial lakes should be identified for the GLOF estimate point of view.
- Using the ICIMOD criteria, Christian Huggel, and Mountain Research Development (MRD) empirical equations, the approximate volume of the critical glacial lakes and their depth can be estimated.
- A criticality analysis of the potential glacial lakes should be carried out to identify and select one or two glacial lakes for GLOF simulation. For criticality analysis, parameters like the volume of the glacial lake, the distance of the lake from the project site, and average slope of the river from the lake up to the project site, the possible combination of lakes, .etc should be considered.

- GLOF simulation is a dam break simulation. The dam break simulation and hydro-dynamic channel routing of the dam break flood from the lake site to the project site to get the magnitude of flood peak at the project site should be carried out using appropriate mathematical models like MIKE-11 HEC-RAS, etc. River cross-sections can be extracted from COPERNICUS, ALOS DEM, SRTM, or other available DEM for hydro-dynamic channel routing.

8. GLOF CASE STUDY FOR SIRKARI BHYOL-RUPSIABAGAR HEP

(a) Brief description of the project

Sirkari Bhyol-Rupsiabagar HEP is a run-of-river scheme that envisages the construction of a barrage 12 m high across the Goriganga river with an underground powerhouse on the right bank with an installed capacity of 168 MW (4x42) in Pithoragarh district of Uttarakhand state. The diversion structure is located at latitude 30011’6” N and longitude 80014’16” E.

Goriganga originates from the Milam glacier northeast of Nanda Devi and is fed from several streams flowing from the eastern slopes of Nanda Devi sanctuary and those flowing west from the high peaks of Panchuchuli, Rajramba, Ralamgad. Goriganga is a perennial river. After flowing for 92 km from its origin in the southeast direction, the river joins Maha Kali about 1 km downstream of the Jauljibi G & G&D site of CWC. After its confluence with Maha Kali, the river is called the Sarda river, which joins further downstream with the Karnali river and is called Sarayu in Bahraich district, Uttar Pradesh, till it joins the Ganga river.

The total catchment area of Goriganga at Sirkari Bhyol-Rupsiabagar HEP diversion site is about 960 sq. km, out of which about 536 sq. km lies above the permanent snow line (EL 4560m). The elevation in the catchment ranges from more than 6000m in upper reaches to around 2180m near the dam site. The entire catchment of Goriganga lies in the state of Uttarakhand between latitude 29045’N to 30036’N and longitude 79059’E to 80028’E.

The inventory of glacial lakes for the project’s catchment has been prepared using the latest LANDSAT 8 ETM+, RESOURCESAT, LISS III/LISS IV multispectral data, as well as Google Earth Pro. The inventory of glacial lakes in the project catchment is given in Annexure-I. The project catchment model depicting glacial lakes is presented in Fig. 7.

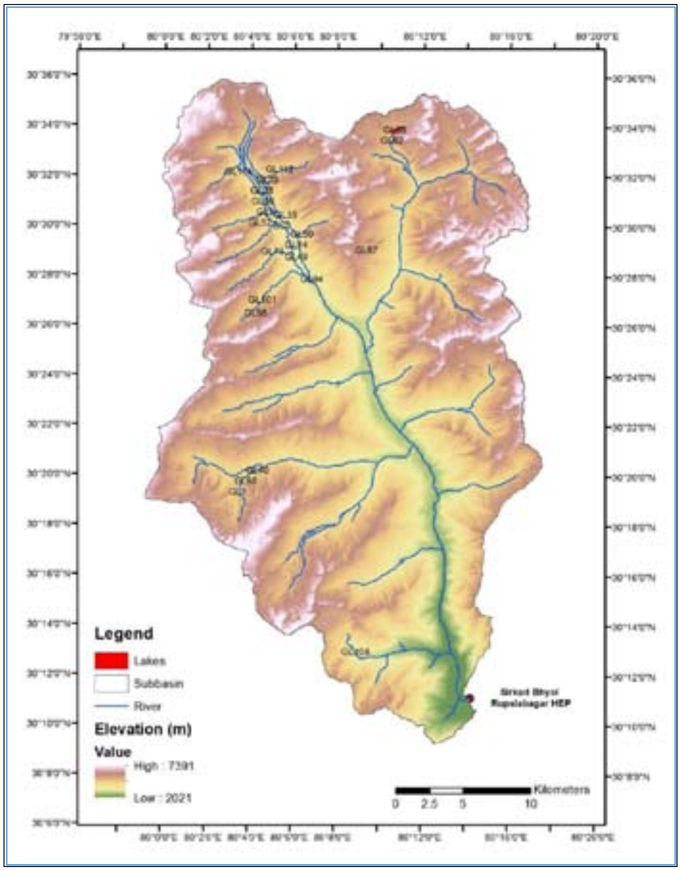

Fig. 7 : Catchment map of Sirkari Bhyol-Rupsiabagar HEP depicting glacial lakes

(b) Potential dangerous glacial lakes

There are about 119 glacial lakes in the catchment area of the Sirkari Bhyol-Rupsiabagar HE project. About 116 glacial lakes are tiny in size, having a surface area lesser than 0.5 hectares (5000 sq.m). Further, almost all the 116 lakes are supraglacial lakes formed on the surface of the glaciers. To identify potentially dangerous glacial lakes for the present case, only the glacial lakes with a surface area of more than 0.5 hectares are considered. There are three moraine-dammed glacial lakes in the project's catchment area, with a surface area (water spread area) of more than 0.5 hectares. The same has been identified for criticality analysis. Based on the criteria discussed below, the identified three glacial lakes in Table-1 may be considered potentially dangerous. The 3D models of these lakes are given in Annexure-II.

The glacial lake GL62 having a surface or water spread area of about 0.556 hectares, is located at an elevation of about 4870 m. From the 3-D model of the lake, it can be said that the lake is an erosion-type glacial lake. This glacial lake is about 200 m downstream of a larger moraine dam, glacial lake GL65. In the possible event of the bursting of GL65, the flood will pass through GL62, resulting in an outburst of this lake. Hence, GL62 may be considered a potentially dangerous glacial lake considering the above aspects.

The glacial lake GL65, with a surface area of about 21.09 hectares, is located at an elevation of 4875 m. It is an end moraine glacial lake formed at the snout of a small valley glacier. The glacier snout is in contact with the lake. The periphery of the lake is bounded by Steep Mountain, where the possibility of a snow avalanche cannot be ruled out. Further, breaking of ice mass from glacier snout due to calving of the glacier may also create a surge wave into lake water resulting in GLOF. Hence, GL65 may be considered a potentially dangerous glacial lake considering the above aspects.

The glacial lake GL87, with a surface area of about 0.647 hectares, is located at an elevation of 5080 m. It is an end moraine dam glacial lake formed at the snout of a small valley glacier. The glacier snout is in contact with the lake; hence there is a possibility of calving of glacier snout and icefall in the lake, resulting in bursting of the lake. Similar to GL 65, here also, steep Mountain bounds the periphery of the lake, and the possibility of a snow avalanche cannot be ruled out. The above features make Lake GL87 a potentially dangerous glacial lake.

Table 1: Potentially dangerous glacial lakes in Sirkari Bhyol-Rupsiabagar HE project catchment

Lake No.	Latitude (N)	Longitude (E)	Elevation (m)	Surface area (ha)	Riverine distance from diversion site (km)	Type	Remarks
GL62	30°33′37.99”	80°10′30.22”	4870	0.556	49.8	End moraine	Potentially dangerous
GL65	30°33’51.76”	80°10’42.16”	4875	21.09	50	End moraine	Potentially dangerous
GL87	30°29’2.20”	80°9’20.90”	5080	0.647	41	End moraine	Potentially dangerous

(c) Criticality analysis to finalize the glacial lake for GLOF Simulation

The two most important parameters for the criticality analysis are the size/volume of the lakes and their distance from the proposed project site. These two parameters influence the lake outburst flood hydrograph and its attenuation pattern. For the present case, all the potentially dangerous glacial lakes are end-moraine lakes. In the absence of any hydrographic survey data, it is not possible to get the exact volume of glacial lakes. Moreover, the hydrographic survey at these extreme locations of glacial lakes is also not possible due to hazardous and inaccessible terrain. However, to get a realistic estimate of the lake volume, the International Centre for Integrated Mountain Development (ICIMOD), Christian Huggel, and Mountain Research and Development have suggested some methodologies. The same is given below:

8.3.1 *ICIMOD*

As per International Centre for Integrated Mountain Development, ICIMOD (2001) “Inventory of Glaciers, Glacial Lakes and Glacial Lakes Outburst Floods” for Bhutan and Nepal, the average depth of a glacial lake formed by different causes can be roughly estimated as follows: cirque lake, 10m; moraine lake, 30m; trough valley lake, 25m; blocking lake and glacier erosion lake, 40m, lateral moraine lakes, 20m. The water reserves of different glacial lakes can be obtained by multiplying their average depth by their area (LIGG/WECS/NEA 1988).

8.3.2 *Christian Huggel*

Another estimate of the depth of glacial lakes can be made from the empirical relationship developed by Huggel et al. (2002) based on the data of the Swiss Alps and tested for some of the glacial lakes such as Raphstreng (Bhutan), Tsho Rolpa, Tholagi, and Lower Barun (Nepal)) of Himalayas also. The Huggel's relationship is for moraine-dammed glacial lakes forming at the lower part of the ablation area of the mother glacier. As per Huggel's empirical equation:

$D = 0.104.\ A^{0.42}$

$V = 0.104.\ A^{1.42}$

A = Surface/Water spread area of the glacial lake (m^2)

D = Depth of the glacial lake (m).

V = volume of the glacial lake (m^3)

8.3.3 *Mountain Research and Development (MRD)*

Based on the surface area and volume data of 33 glacial lakes in the HKH region, MRD has derived the following empirical equation:

$V = 0.0578A^{1.4683}$

A = Surface/Water spread area of the glacial lake (m^2)

V = volume of the glacial lake (m^3)

Considering the Huggel and MRD empirical equations, the volume of the different glacial lakes has been estimated as mentioned in Table 2.

Table 2 : Potentially dangerous glacial lakes in Sirkari Bhyol-Rupsiabagar HE project catchment and their estimated volume

Lake No.	Elevation (m)	Surface area (ha)	Estimated Volume by MRD equation (MCM)	Estimated Volume by Huggel equation (MCM)	Average volume as per Col 4 and 5 (MCM)	Depth (m)	Riverine distance from diversion site (km)
1	2	3	4	5	6	7	8
GL62	5070	0.556	0.018	0.022	0.020	3.9	49.8
GL65	5060	21.09	3.796	3.778	3.787	17.9	50
GL87	4710	0.647	0.023	0.027	0.025	4.1	41

The estimated volume from MRD and Huggel formula are almost comparable. Hence, for a conservative estimate, it is appropriate to take the volume of lakes as the average of Huggel and MRD formulas estimate. Further, considering the lake volume and distance from the project site, GL65 with an estimated volume of 3.787 MCM and estimated depth of 17.9 m can be considered the most critical glacial lake for the GLOF estimate of Sirkari Bhyol-Rupsiabagar HEP. Further, as discussed above, GL62 is about 200 m downstream of GL65, and GLOF of GL65 shall pass through GL62, hence for GLOF simulation, the combined volume (3.807 MCM), which is the total of GL65 and GL62, should be considered. For the Glacial Lake Outburst Flood study, the GLOF simulation has been carried out, taking a conservative depth of 20 m and a volume of 4 MCM considering the combination of GL65 and GL62.

9. CONCLUSION

The Indian Himalayan region is the key to securing green energy to meet the ever-rising energy requirements of a country like India. Indian economy is growing at a fast pace, and at present, it is the sixth-largest economy in the world with a GDP of about 3.05 trillion dollars. To keep pace with this growth, India has to develop its untapped hydro-potential in the Himalayan region. It poses a conflict of interest between economic development and environmental conservation. Global warming, fragile mountain cryosphere, threats of landslides, GLOF, avalanches, and other flash flood events are severe challenges for the safety of river valley projects and mountain communities. The glacial lake outburst flood study is vital to address the challenges of associated risks with flashflood.

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ANNEXURE-I

Inventory of Glacial Lakes in The Catchment of Sirkari Bhyol-Rupsiabagar HE Project

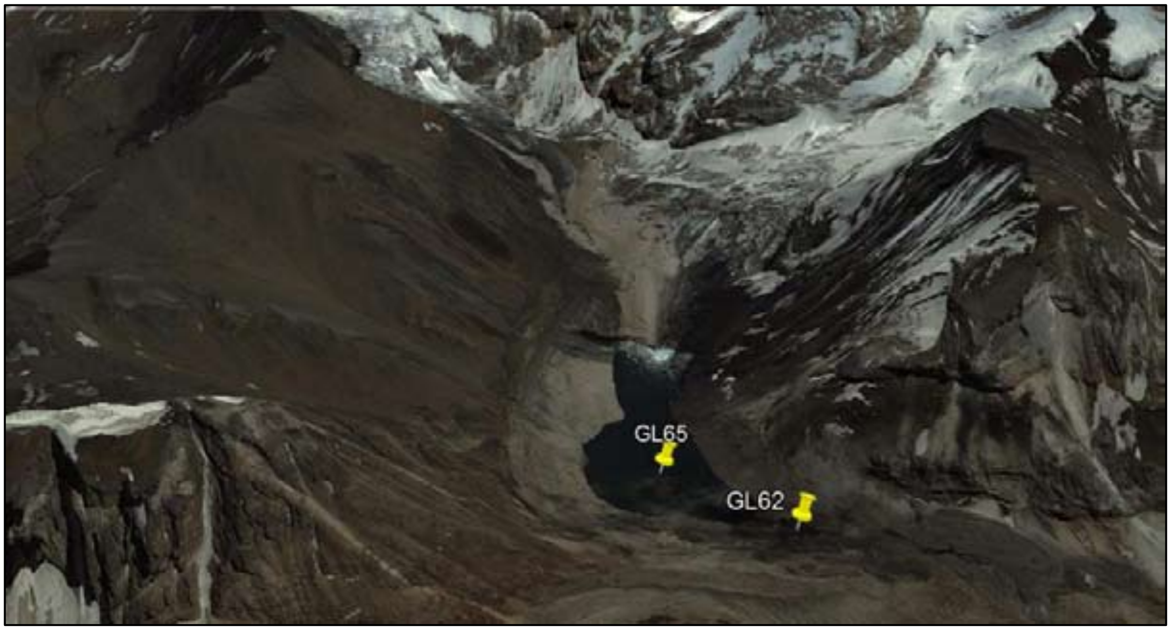
Glacial lake_ID	Latitude (North)	Longitude (East)	Surface Area (ha)
GL1	30°19´24.97343844”	80°3´29.6937864”	0.061
GL2	30°29´59.90874252”	80°5´23.34939972”	0.243
GL3	30°30’2.22311952”	80°5’14.4342312”	0.020
GL4	30°30´8.65580256”	80°5´7.3368168”	0.071
GL5	30°30’7.03759968”	80°5’2.36117868”	0.034
GL6	30°30´4.84437168”	80°5´3.53464764”	0.017
GL7	30°30’12.66811848”	80°4’51.86777952”	0.056
GL8	30°30´25.39712628”	80°4´50.68085124”	0.037
GL9	30°30’39.043647”	80°4’38.99413092”	0.177
GL10	30°31´18.68510604”	80°4´15.7803798”	0.011
GL11	30°31’19.30970028”	80°4’17.49127296”	0.014
GL12	30°31´19.88479992”	80°4´25.8285576”	0.078
GL13	30°28’53.16053664”	80°6’5.96337084”	0.022
GL14	30°29´13.88432436”	80°6´6.15701736”	0.164
GL15	30°29’22.43300244”	80°6’2.46716496”	0.011
GL16	30°29´26.91359628”	80°6´8.88405804”	0.039
GL17	30°31’50.10406644”	80°4’35.32656504”	0.044
GL18	30°31´52.96604124”	80°4´41.38876452”	0.016
GL19	30°29’9.86358516”	80°6’14.26799304”	0.008
GL20	30°31´40.777167”	80°4´42.18668292”	0.071
GL21	30°31’38.01072324”	80°4’42.36578868”	0.032
GL22	30°30´35.25462684”	80°4´41.70774612”	0.138
GL23	30°30’27.42497352”	80°4’57.82221372”	0.012
GL24	30°30´53.11885428”	80°4´52.67132796”	0.030
GL25	30°31’12.5538708”	80°4’23.94600528”	0.014
GL26	30°31´15.98278548”	80°4´28.58643444”	0.013
GL27	30°31’13.00302156”	80°4’30.61000344”	0.036
GL28	30°31´15.89729196”	80°4´30.13293396”	0.124
GL29	30°31’14.63448648”	80°4’30.88367364”	0.025
GL30	30°31´12.54302292”	80°4´39.35681616”	0.035
GL31	30°31’11.0164548”	80°4’44.5050786”	0.011
GL32	30°31´10.95949452”	80°4´39.99288576”	0.033
GL33	30°29’43.22386752”	80°6’1.10772756”	0.015
GL34	30°29´59.90675532”	80°5´44.28570336”	0.018
GL35	30°30’19.16816112”	80°5’26.93078124”	0.030
GL36	30°30´58.51415736”	80°4´32.10806352”	0.446
GL37	30°31’2.57060244”	80°4’35.21187264”	0.029
GL38	30°31´4.24413876”	80°4´38.18917524”	0.023
GL39	30°31’2.86740084”	80°4’33.61576692”	0.064
GL40	30°20´10.88472084”	80°4´23.25279864”	0.297

GL41	30°20’6.83161116”	80°4’15.73946724”	0.010
GL42	30°19′34.5853236”	80°3′26.068824”	0.007
GL43	30°19’32.5998084”	80°3’25.89487884”	0.014
GL44	30°19′10.47217656”	80°3′25.48612944”	0.013
GL45	30°19’6.33570564”	80°3’34.5173274”	0.017
GL46	30°28′42.22099452”	80°6′3.0242466”	0.012
GL47	30°28’39.5307156”	80°6’5.30879724”	0.005
GL48	30°28′41.54283732”	80°5′58.75156212”	0.007
GL49	30°28’45.64464132”	80°6’5.87561508”	0.073
GL50	30°29′32.488269”	80°6′7.64089704”	0.062
GL51	30°29’31.2898074”	80°6’7.42818708”	0.031
GL52	30°30′17.5019958”	80°4′55.33256208”	0.189
GL53	30°30’16.62393672”	80°4’58.8491724”	0.012
GL54	30°30′17.56034064”	80°4′50.08382616”	0.013
GL55	30°30′18.0463806”	80°4′50.4167718”	0.012
GL56	30°30′26.64054468”	80°4′41.3330592”	0.015
GL57	30°30’37.59879024”	80°4’35.24754648”	0.038
GL58	30°30′47.95417476”	80°4′39.38028672”	0.013
GL59	30°30’52.89881436”	80°4’44.51382516”	0.038
GL60	30°30′54.7362162”	80°4′42.53417292”	0.038
GL61	30°30’58.78211004”	80°4’38.44547292”	0.014
GL62	30°33′37.99818036”	80°10′30.21707172”	0.556
GL63	30°33’34.6582854”	80°10’33.12314724”	0.102
GL64	30°33′31.97647188”	80°10′32.85609564”	0.058
GL65	30°33’51.7564782”	80°10’42.1592808”	21.092
GL66	30°19′55.30673604”	80°3′51.480054”	0.122
GL67	30°20’11.99730588”	80°4’25.12470864”	0.023
GL68	30°19′43.384953”	80°3′29.79953172”	0.114
GL69	30°19’41.01262248”	80°3’32.9654232”	0.009
GL70	30°19′26.3595306”	80°3′28.87207308”	0.018
GL71	30°19’41.21870016”	80°3’33.64622964”	0.019
GL72	30°28′58.9321884”	80°5′9.85285428”	0.008
GL73	30°28’58.5866334”	80°5’20.78211228”	0.024
GL74	30°30′3.3195132”	80°5′9.99113244”	0.014
GL75	30°29’6.57754584”	80°6’6.95272572”	0.010
GL76	30°29′23.87806008”	80°6′10.57216248”	0.004
GL77	30°30’8.65745388”	80°5’10.71235536”	0.010
GL78	30°30′9.67422492”	80°5′12.48612108”	0.009
GL79	30°30’15.83881848”	80°5’9.88787148”	0.007
GL80	30°30′43.67685924”	80°4′52.16731788”	0.039
GL81	30°30’45.8382024”	80°4’54.50078424”	0.078
GL82	30°30′46.01948904”	80°4′49.85987196”	0.014
GL83	30°31’37.58593008”	80°4’25.57038216”	0.018

GL84	30°31´40.02926016”	80°4´18.03509112”	0.010
GL85	30°31’57.82420488”	80°4’25.61805984”	0.010
GL86	30°29´9.87850284”	80°9´14.2394922”	0.019
GL87	30°29’2.20181928”	80°9’20.90149632”	0.647
GL88	30°28´31.03243536”	80°6´25.65608184”	0.013
GL89	30°29’13.52726736”	80°6’13.71918564”	0.005
GL90	30°31´31.3325724”	80°4´35.57492508”	0.006
GL91	30°31’26.15615688”	80°4’5.58073668”	0.015
GL92	30°31´54.37239636”	80°3´53.14149972”	0.017
GL93	30°31’18.71324436”	80°4’14.53761012”	0.005
GL94	30°27´52.0539048”	80°6´49.21107084”	0.037
GL95	30°26’35.5414902”	80°4’4.94651964”	0.031
GL96	30°26´32.99318664”	80°3´52.86431664”	0.028
GL97	30°26’31.79099328”	80°4’0.89427792”	0.018
GL98	30°26´29.28736896”	80°4´14.68771248”	0.140
GL99	30°26’24.59776812”	80°3’58.61246616”	0.067
GL100	30°26´28.19233932”	80°4´3.60006996”	0.118
GL101	30°27’1.90588428”	80°4’33.41256564”	0.009
GL102	30°27´2.78863524”	80°4´35.23196928”	0.003
GL103	30°30’21.7600434”	80°5’7.03283964”	0.006
GL104	30°30´44.49674592”	80°4´35.15149308”	0.008
GL105	30°30’56.69892972”	80°4’29.47057644”	0.016
GL106	30°30´56.19798396”	80°4´30.06037272”	0.014
GL107	30°31’17.04555228”	80°4’12.3279924”	0.003
GL108	30°12´55.27073772”	80°8´58.15569948”	0.037
GL109	30°20’3.8097492”	80°4’17.27909328”	0.017
GL110	30°29´12.60399948”	80°6´3.99986244”	0.011
GL111	30°31’13.55692476”	80°4’16.95052128”	0.014
GL112	30°32´12.634944”	80°5´18.81909168”	0.020
GL113	30°32’8.06244252”	80°5’8.00857608”	0.006
GL114	30°32´8.99197008”	80°3´24.30418968”	0.038
GL115	30°32’9.89744748”	80°3’20.40367788”	0.014
GL116	30°32´8.61172512”	80°3´38.09559096”	0.004
GL117	30°32’7.92213936”	80°3’38.9529342”	0.003
GL118	30°32´16.28138904”	80°3´30.31109208”	0.005
GL119	30°32´15.10910844”	80°3´33.39575568”	0.005

ANNEXURE-II

3D Models Of Potentially Dangerous Glacial Lakes



GL65 and GL62

GL87