Inventory of glacial lakes and identification of PDGLs

in Koshi, Gandaki and Karnali basins of Nepal, TAR of China and India

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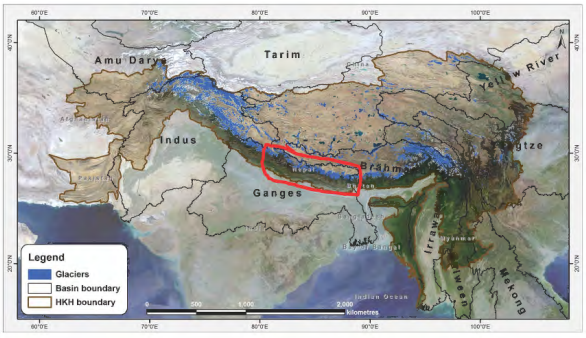
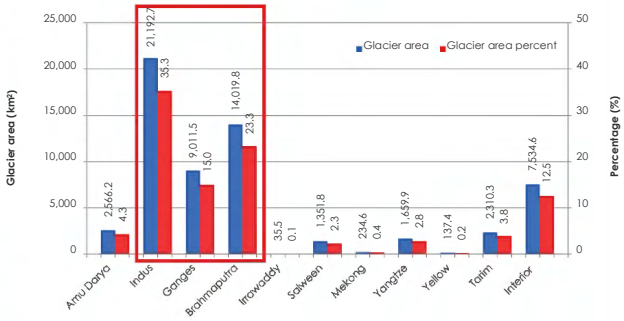
The Hindu Kush Himalaya Region





HKH area: 4.19 million km^2

The Hindu Kush Himalaya (HKH) region extends 3500 km over all or part of eight countries, ranging from Afghanistan in the west to Myanmar in the east.

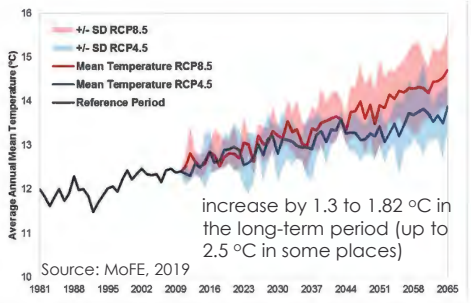
- It is the source of countless perennial rivers that originate from glaciers.
- It is also the source of various natural disasters such as snow avalanche, glacial lake outburst floods (GLOF).

Climate change and its impact on glaciers and glacial lakes in Nepal

Trend in annual maximum temperature in Nepal was significantly positive, **at 0.056°C/yr over 1971–2014** (DHM 2017)

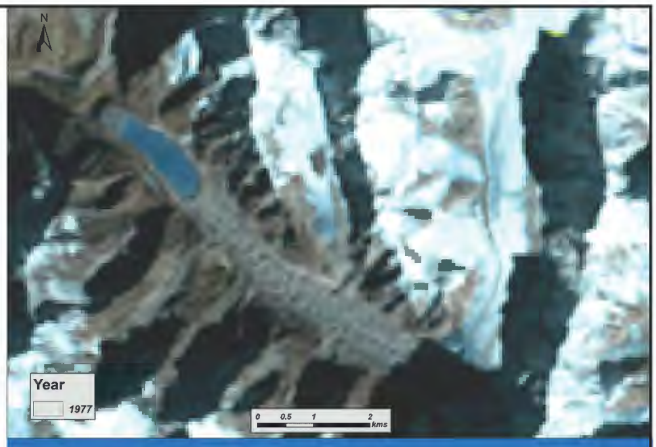
Greater warming rate of **0.086°C/year** in the **Higher Himalaya** over that period

Mountains are warming more than the plains



increase by 1.3 to 1.82 °C in the long-term period (up to 2.5 °C in some places)

Source: MoFE, 2019



- Glacier area has decreased and number increased due to retreat, shrinkage and fragmentation.
- Glacial lake number and area has increased
- Glacier areas in Nepal decreased by 24% in the 33 years between 1977 and 2010
- The total lake area increased by 12% in the Koshi basin, 8% in the Gandaki basin, and 1.27% in the Karnali basin between 2000 and 2015.

Glacial Lakes

- Glacial melt water dammed by – Ice, moraine(debris), bedrock, landslide or alluvial fan
- Area ≥0.003 km^2 (at least 3-4 pixels in 30 m resolution satellite image)
- Elevation above 3000 masl.

Limitations

✓Rugged terrain

✓High elevation

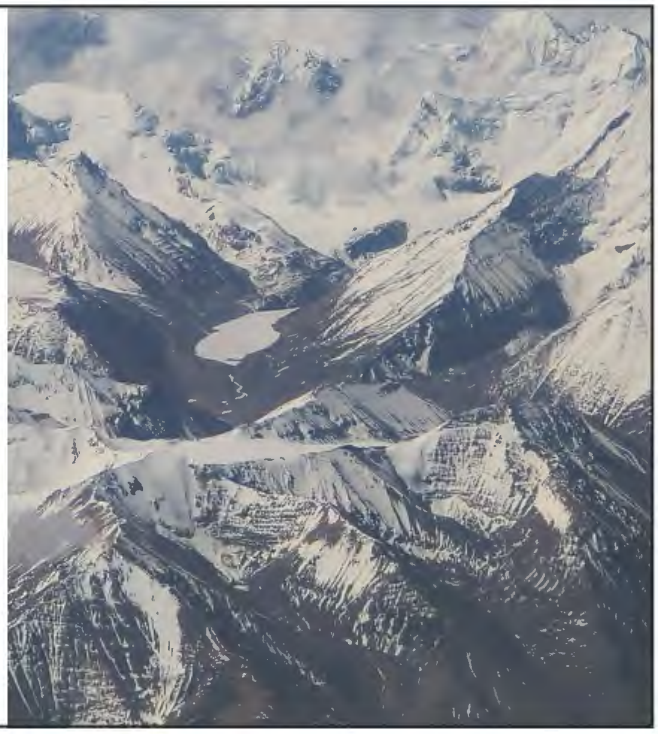
✓Remote area

✓Expensive field survey

✓Time consuming

✓Man power

Remote sensing is the best tool to map the glacial lakes



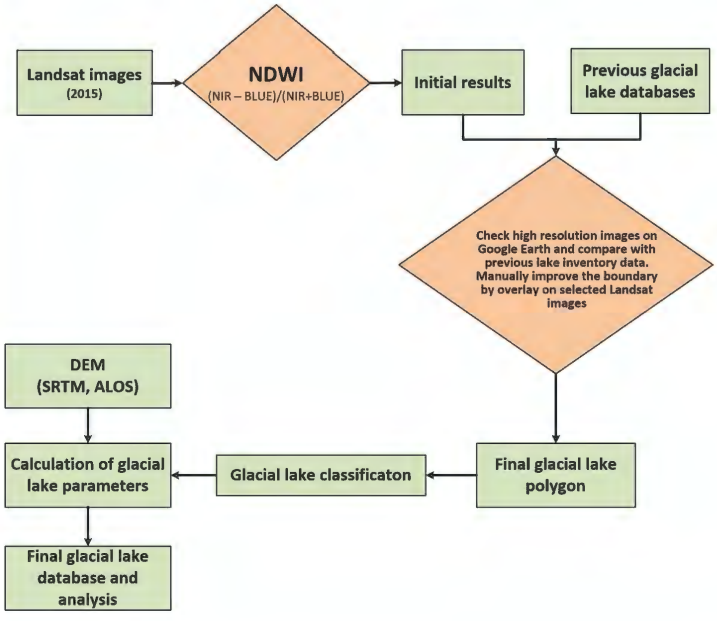
Mapping method

- Semi-automatic
- 97% accuracy

- Lake Id
- Latitude / Longitude
- Lake area
- Elevation
- Lake type

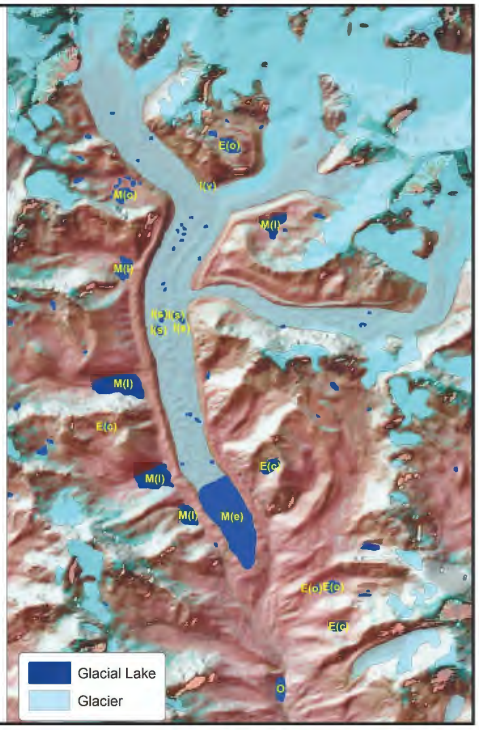
- Landsat 8 (2015±1)
- High resolution images in Google earth.

- 5m DEM for Nepal part
- 12.5 m DEM outside Nepal



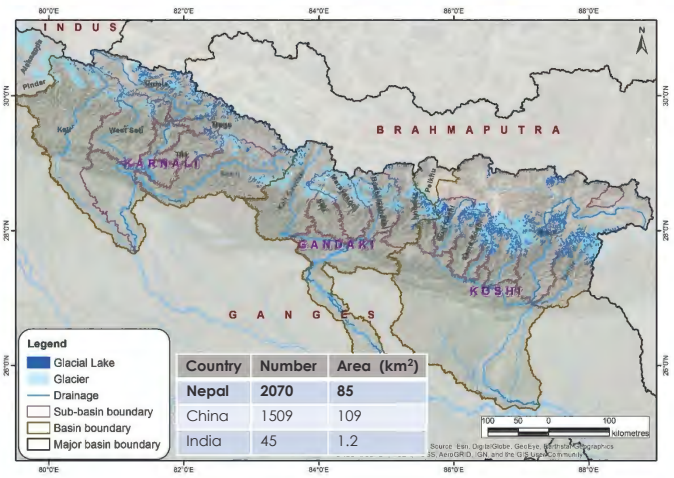
Glacial Lake classification

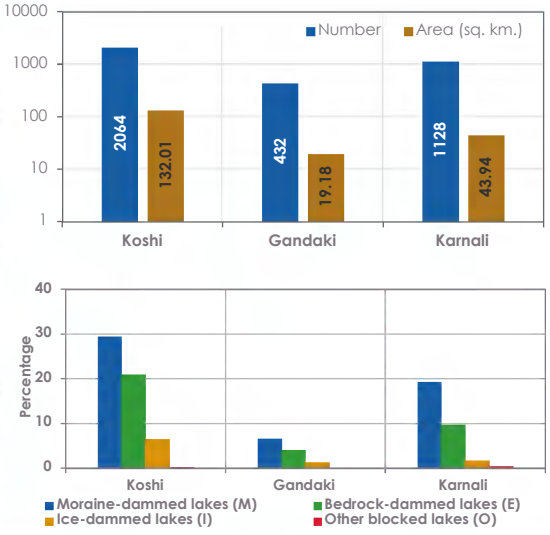
S.N.	Glacial lake type		Description
1	Moraine Dammed Lake **(M)**	End Moraine Dammed Lake - **M(e)**	The lake's water usually touches the walls of the side moraines, but the water is held back by the end moraine (dam), but not necessarily, in contact with the glacier, and may have glacier ice at the lake bottom.
2		Lateral Moraine Dammed Lake - **M(l)**	Lake formed in the tributary valley, trunk valley, or between the lateral moraine and the valley wall, or at the junction of two moraines. Lake is held back by the outside wall of a lateral moraine
3		Other Moraine Dammed Lake - **M(o)**	Lake dammed by other moraines (includes kettle lakes and thermokarst lakes).
4	Ice Dammed Lake **(I)**	Supra Glacial Lake - **I(s)**	Body of water (ponds or lakes) on the surface of a glacier
5		Dammed by tributary-valley glacier **- I(v)**	Lake dammed by glacier ice with no lateral moraines. Can be at the side of a glacier between the glacier's margin and valley wall
6	Bedrock dammed Lake **(B)**	Cirque Lake - **B(c)**	A small pond occupying a cirque
7		Other Glacier Erosion Lake - **B(o)**	Body of water occupying depressions formed by glacial erosion. These are usually located on the mid-slope of hills, but not necessarily in a cirque
8	Other dammed Lakes **(O)**		Lakes formed in a glaciated valley and fed by glacier melt, but the damming material is not directly part of the glacial process, for example, debris flow, alluvial, or landslide-blocked lakes



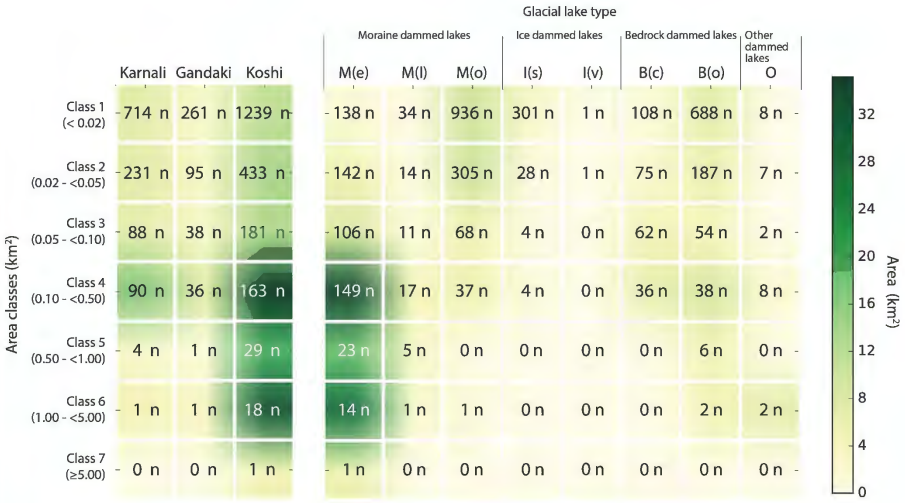
Glacial Lakes in Koshi, Gandaki & Karnali

3624 glacial lakes covering 195 km² surface area were mapped.





Size and type



Lakes larger than 0.02 km^2 = 1410 (39%)

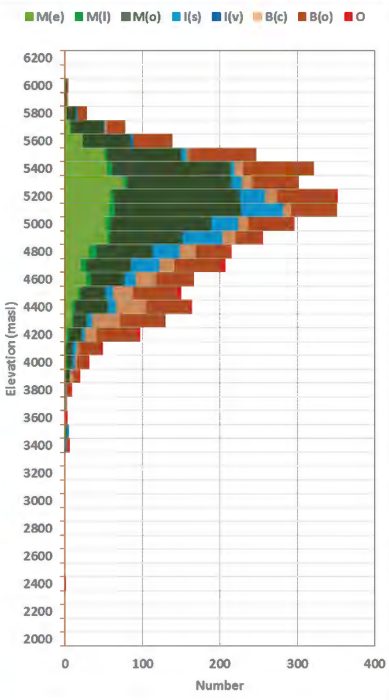
Moraine dammed lakes = 2002 (55%)

Altitudinal distribution

Elevation ranges from 3400 to 6100 masl

More than **98% of lakes** are between **4000 to 6000 masl**

Elevation Zone		3,000–4,000		4,000–5,000		5,000–6,000		6,000– 7,000		Total	
Type		No	%	No	%	No	%	No	%	No	%
M	M(e)	7	15.6	180	12.3	386	18.3	0	0	573	15.8
	M(l)	0	0	43	2.9	37	1.8	2	50	82	2.3
	M(o)	6	13.3	387	26.5	953	45.1	1	25	1347	37.2
I	I(s)	7	15.6	178	12.2	152	7.2	0	0	337	9.3
	I(v)	0	0	0	0	2	0.1	0	0	2	0.06
	I(o)	0	0	0	0	0	0	0	0	0	0
B	B(c)	7	15.6	202	13.8	72	3.41	0	0	281	7.8
	B(o)	12	26.7	452	31.0	510	24.1	1	25	975	26.9
Others	O	6	13.3	18	1.2	2	0.1	0	0	26	0.75
Total		45	1.2	1460	40.3	2114	58.3	4	0.1	3623	100



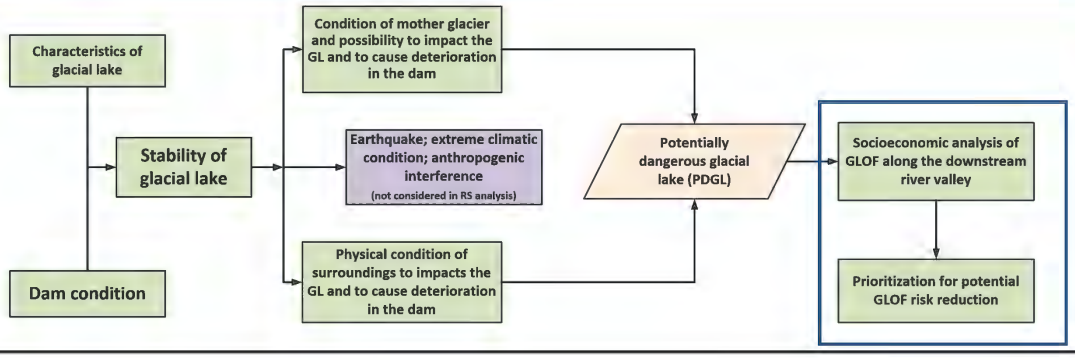
Identification of Potential Dangerous Glacial Lakes

Level 1: Lake characteristics

Level 2: Dam characteristics

Level 3: Characteristics of source glaciers

Level 4 : Physical condition of surroundings



Lake stability

Lake characteristics

- Lake size and rate of expansion;
- Increase in the water level/volume of water;
- Presence of cascading lakes; and
- Intermittent activity of supraglacial lakes

Source glacier

- Condition of associated glacier (source glacier);
- Distance between the lake and glacier(s);
- Steepness of glacier tongue;
- Debris cover on the lower glacier tongue;
- Presence of crevasses and ponds on the glacier;
- Calving of ice from the glacier's snout; and
- Icebergs breaking off at the glacier terminus

Dam characteristics

- Type of damming material;
- Crest width;
- Slope of the dam wall;
- Height and length of the dam;
- Landslides on the dam;
- Presence or absence of drainage outflow;
- GLOF in the past;
- Seepage through the dam's walls; and
- Existence of ice core and/or permafrost

Surrounding physical conditions

- Hanging glaciers in contact or close to the lake;
- Potential rockfall/slide around the lake;
- Large snow avalanche close to the lake; and
- The sudden advance of a glacier towards a lower tributary or the main glacier which has a well-developed frontal lake.

Analysis for PDGL

Total lakes (lakes larger than 0.003 km^2) - **3624 lakes**

Level 1: Lake characteristics

Total lakes – Class 1 (<0.02 km^2) – type {(I(s+v) – B(c+o) – O)}

3624 - 2214 - 37 – 460 -19 = **895**

A total of 2729 lakes removed from Level 0

Level 2: Dam characteristics

Level 1 – no crest(nc) – compressed and old dam material(co) – dam length > 500m (dl) – dam outer slope < 20 degree = **295**

A total of 600 lakes removed from Level 1

Analysis for PDGL

Level 2 analysis - 295

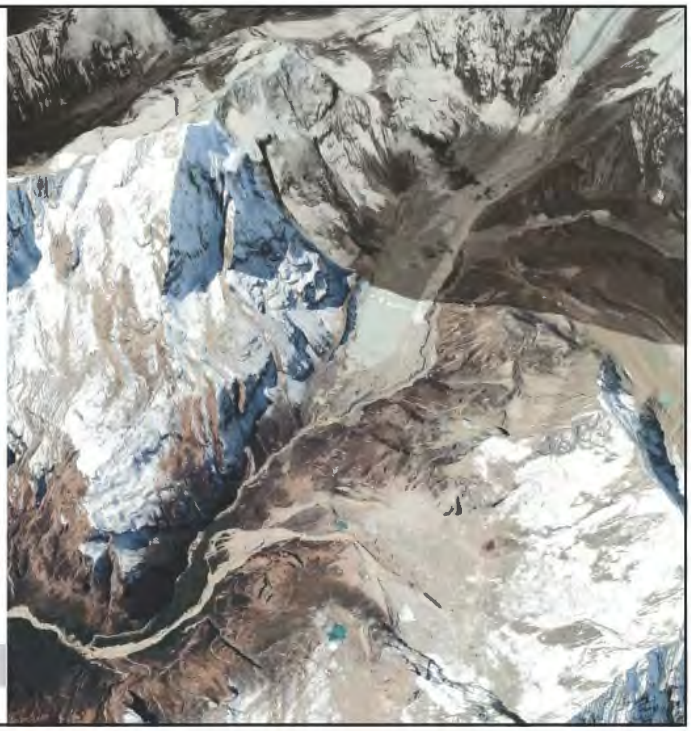
Level 3: Source glacier

- more than 200m away (dm),
- glaciers slopes less than 20 degrees (sm)

Level 4: Physical Condition of Surroundings

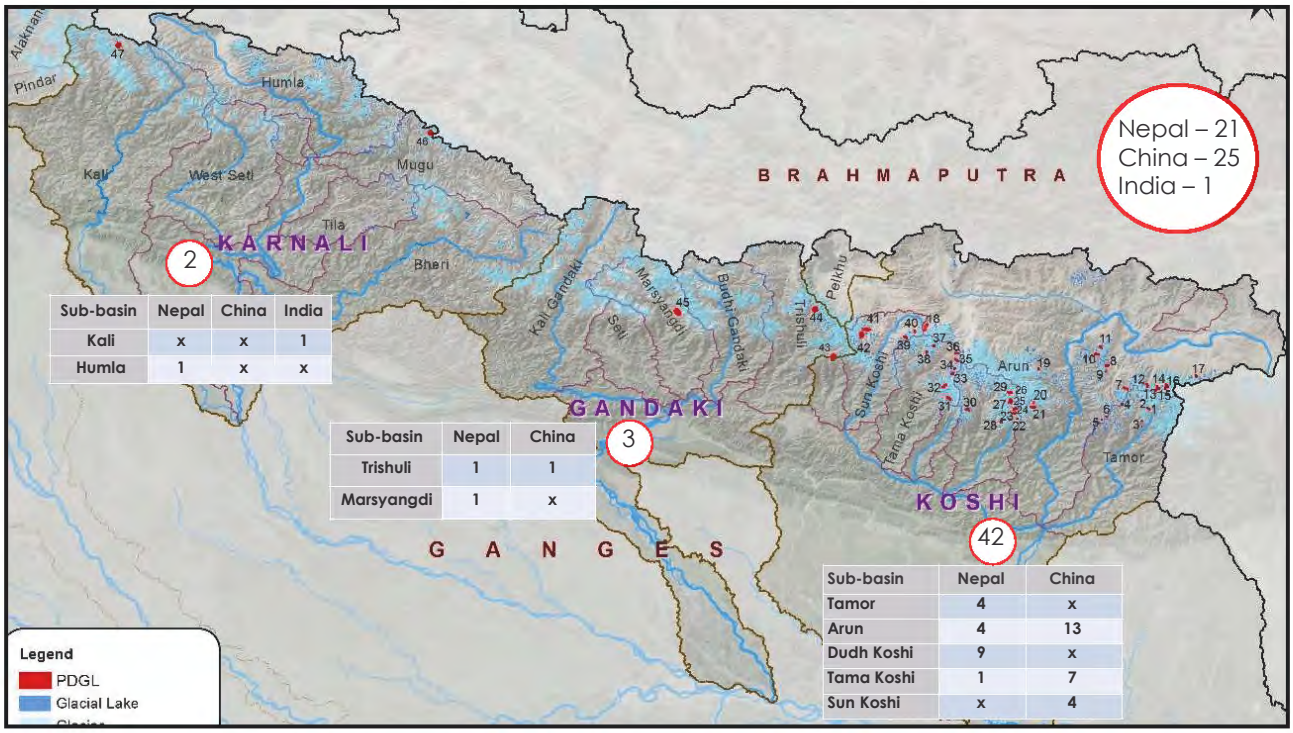
- Probability of snow/ice avalanches
- Potential landslides

A total of 47 lakes is selected as PDGLs



Analysis for PDGL

Country	Basin	Lake inventory	Lake character.	Dam character.	Source gr. and surroundings	PDGL
		level 0	Level 1	Level 2	Level 3	Level 4
Nepal	Koshi	834	199	91	19	18
	Gandaki	255	65	18	2	2
	Karnali	981	241	39	1	1
	Sub-total	**2,070**	**505**	**148**	**22**	**21**
China	Koshi	1,230	308	123	28	24
	Gandaki	177	52	17	1	1
	Karnali	102	22	3	0	0
	Sub-total	**1,509**	**382**	**143**	**29**	**25**
India	Koshi	0	0	0	0	0
	Gandaki	0	0	0	0	0
	Karnali	45	8	4	1	1
	Sub-total	**45**	**8**	**4**	**1**	**1**
Total		**3,624**	**-2729 895**	**-601 295**	**-243 52**	**-5 47**



Ranking of PDGLs

Rank I Possibility of expansion due to the calving of glaciers, close to the loose moraine end; no overflow through the moraine dam; steep outlet slope; hanging source glacier; chances of snow and/or ice avalanches and landslides in the surroundings impacting the lake and dam.

Rank II Confined lake-outlet; compact old end-moraine; hanging lake; distinct seepage at the bottom of end-moraine dam; gentle moraine slope.

Rank III Confined lake-outlet; gentle outward dam slope; large lake but shallow depth; moraine dam more than 200m; old and compact moraine.

Country	Rank I	Rank II	Rank III	Total
Nepal	15	3	3	21
TAR, China	15	9	1	25
India	1	x	x	1
Total	31	12	4	47

Basin	Rank I	Rank II	Rank III	Total
Koshi	28	10	4	42
Gandaki	2	1	x	3
Karnali	1	1	x	2
Total	31	12	4	47

Conclusion and Way Forward

- **3624 (2,070 in Nepal)** glacial lakes with the size ranging from 0.003 to 5 km^2
- Lakes larger than 0.02 km^2 are 1,410, large enough to damage the settlements and infrastructure
- **47 lakes** are identified as **potentially dangerous** based on stability of lake and dam, source glacier and surroundings
- **21 PDGLs** are in **Nepal**, **25** are in **China** and **1** in **India**
- **Koshi basin - 42 PDGLs** and 18 PDGLs in Nepal
- Number of **Rank I PDGL** is also **high (28 with 15 in Nepal)** in **Koshi basin**

- Formation of new lakes, expansion of existing lakes and disappearing of lakes are common processes - **Repeat inventory of glacial lakes is required**
- Remote Sensing is the best and quick tool – High Resolution imageries and Digital Elevation Model
- **Mechanism for regular monitoring of glacial lakes and GLOF prone areas for effective GLOF hazard management.**
- **Detail field study of high risk (Rank 1) PGDLs is required.**
- Require establishment of **vulnerability of human assets (life and property) in the downstream area.**
- **Need to reduce GLOF risk for sustainable mountain development**
- Installation of real time sensor network and early warning system coupled with GLOF simulation models, to reduce the intensity of disaster associated with the GLOFs
- Create awareness to the peoples living downstream of PDGLs


Thank you
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