Glacier Information Booklet

Know Your Glaciers in the Himalayan Upper Ganga Basin

Prepared by

National Institute of Hydrology, Roorkee

in association with

National Mission for Clean Ganga

Department of Water Resources, River Development & Ganga Rejuvenation
Ministry of Jal Shakti, Government of India

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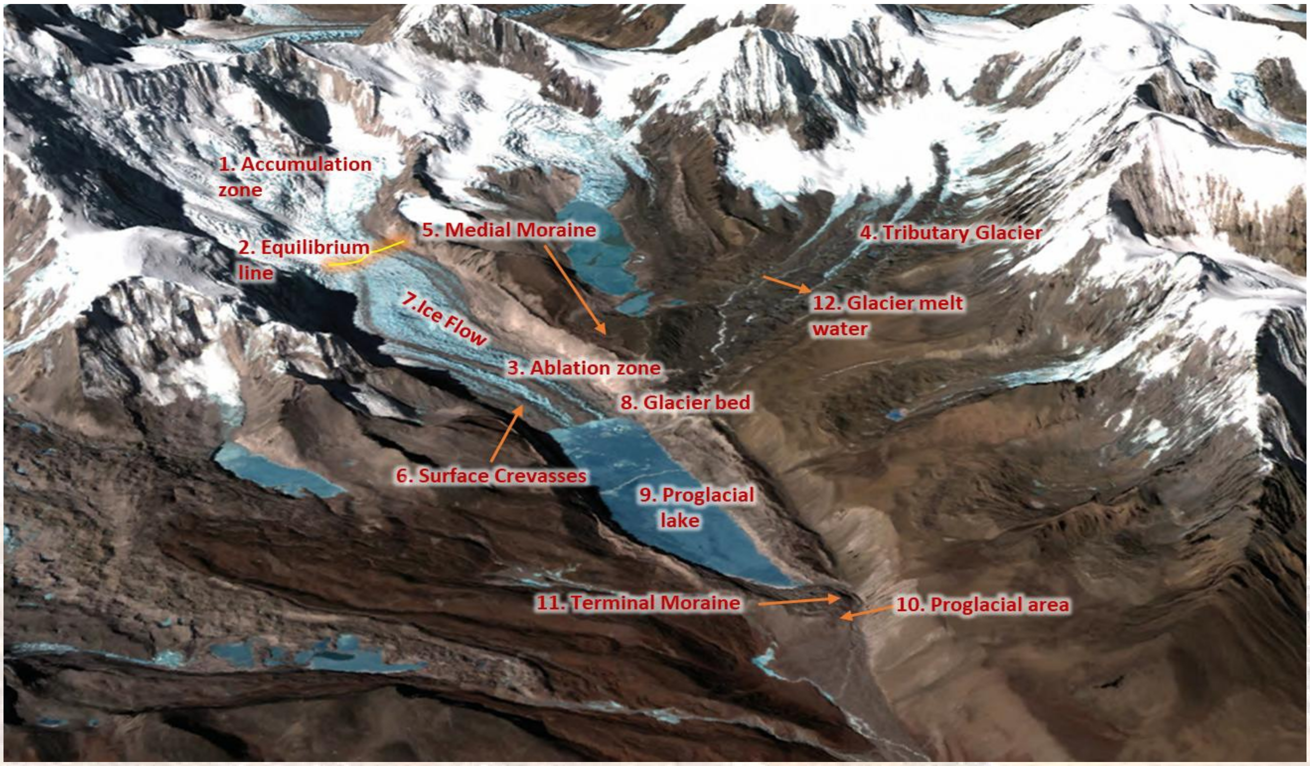
ANATOMY OF A GLACIER

1. **Accumulation Zone**
   The "birthplace" of the glacier at high altitudes (Greater Himalayas).
2. **Equilibrium Line**
   The invisible boundary where the amount of new snow gained equals the amount of ice lost. Above this line, the glacier grows; below it, it recedes.
3. **Ablation Zone (Debris-Covered)**
   The lower "tongue" of the glacier. In the Himalayas, this area is often covered in supraglacial debris (rocks and dust).
4. **Tributary Glacier**
   Smaller glaciers that flow from side valleys to join and feed the main trunk of the glacier, much like streams joining a river.



Location: South Lhonak Glacier & Lake Area, Sikkim

5. **Medial Moraine**
   A long ridge of debris running down the center of the glacier. It forms when two lateral moraines (debris at the edges) meet where two glaciers merge.
6. **Surface Crevasses & Seracs**
   Deep cracks (crevasses) and towering blocks of ice (seracs) formed by the stress of the glacier moving over uneven bedrock.
7. **Ice Flow**
   The glacier moves via Internal Deformation (ice crystals sliding) and Basal Sliding (sliding over a thin layer of water at the bottom).
8. **Glacier Bed**
   The floor consisting of tough Himalayan bedrock (metamorphic or igneous) and Glacial till-the unsorted "ground meal" of rocks and sediment.
9. **Proglacial Lake**
   Instead of calving into the sea, Himalayan glaciers often calve into high-altitude lakes formed behind moraines.
10. **Proglacial Area**
    The valley below the glacier, characterized by Fluvial Outwash
11. **Terminal Moraine**
    The massive wall of rubble deposited at the very end (snout) of the glacier, marking its furthest point of advance.
12. **Glacial Meltwater**
    Glacier ice that discharge water. This is the primary source of major perennial rivers like the Ganga, Indus, and Brahmaputra.

INTRODUCTION: GLACIERS OVERVIEW ACROSS THE HIMALAYAN ARC

The Indian Himalayan Region (IHR) hosts one of the largest concentrations of glaciers outside the polar regions and serves as a vital freshwater reserve for the Indian sub-continent. These glaciers act as natural water storage systems, accumulating winter snowfall and releasing meltwater during warmer months, thereby regulating seasonal river flows and supporting agriculture, hydropower generation, ecosystems, and water supply for millions of people downstream.

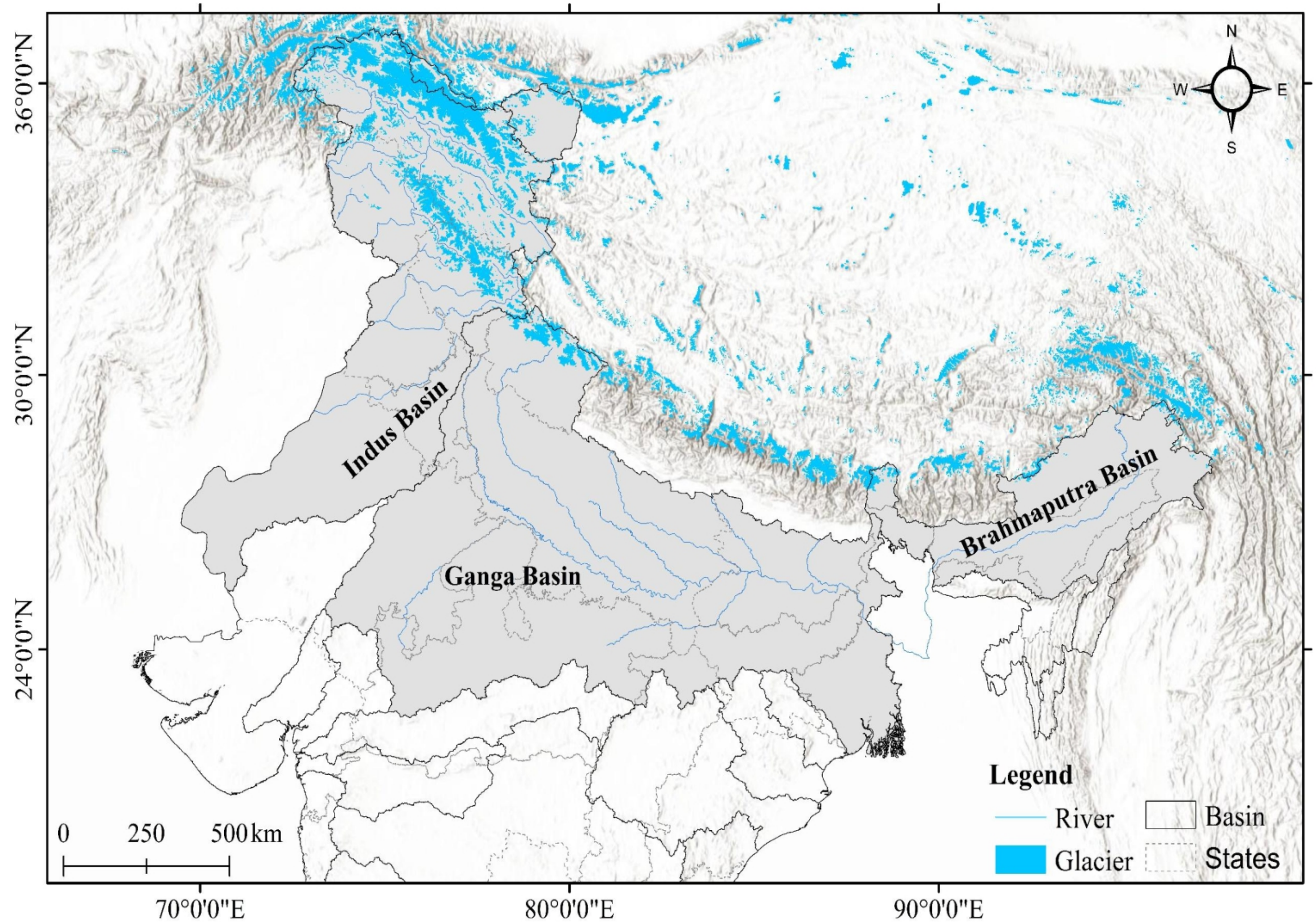
In India, glaciers are primarily distributed across the Indus, Ganga, and Brahmaputra river basins, which together form the major Himalayan river systems. Glacier inventories compiled by the Geological Survey of India (GSI) indicate that the Indus basin contains the largest concentration of glaciers, mainly due to extensive glaciation in the Karakoram and western Himalaya, where colder and relatively drier conditions favour the development of large valley glaciers (Raina & Srivastava, 2008).

Overall, these three basins together host 9,617 glaciers covering about 40,216 km² of glacierized area within the Indian Himalayan Region. These glaciers play a crucial role in maintaining river flow regimes, particularly during the pre-monsoon and summer seasons, when snow and glacier melt contribute significantly to streamflow, making their monitoring and assessment essential for long-term water security and climate change studies.

Key Points:

- Indus Basin has the largest glacierized area in the Himalayan region.
- Ganga Basin has moderate glacier coverage with significant summer glacier melt contribution.
- Brahmaputra Basin hydrology is largely influenced by monsoon rainfall.
- Debris-covered glaciers are common, covering about 20-26% of glacier area across the basins.
- Glacier contribution to river runoff is highest in Indus, moderate in Ganga, and lower in Brahmaputra.
- Valley glaciers dominate the Himalayan glacier system, with the highest proportion in the Ganga basin

GLACIERS ACROSS THE HIMALAYA ARC



Parameters	Indus Basin	Ganga Basin	Brahmaputra Basin
No. of Glaciers (GSI)	8039	968	610
Glacier Area (Km²)	36,431	2,857	928
Debris Cover	~20.6%	~26.3%	~25.6%
Glacier Size Distribution (<1 km²)	~71.7%	~45.2%	~64.5%
Lean Precipitation Period	Dec & Jan	May	Nov
Peak Precipitation Period	July-Aug (~100-150 mm)	July-Aug (~250-350 mm)	July & Aug (~450-600 mm)
Averaged Annual Precipitation	~350-400 mm	~1000-1100 mm	~2100-2300 mm

"In the silent ice of the Himalaya lies the future of millions downstream"

GLACIERS IN THE UPPER GANGA BASIN

The Upper Ganga Basin (UGB) in the Indian Himalaya contains a significant concentration of glaciers that form the headwaters of the Ganga River system. Major glaciered regions occur within the Bhagirathi-Alaknanda, Yamuna, and Ghaghara sub-basins, which together sustain important Himalayan river networks.

Among these, the Bhagirathi-Alaknanda basin contains the largest number and area of glaciers, with about 645 glaciers covering nearly 1,984 km². This region includes several well-known valley glaciers such as Gangotri, Satopanth, Pinder, Doodh Ganga, Khatling and Chorabari, which play an important role in regulating river discharge and maintaining perennial flow in the Bhagirathi and Alaknanda rivers before their confluence at Devprayag.

The Ghaghara basin hosts approximately 271 glaciers with a glacierized area of about 729 km², while the Yamuna basin contains around 52 glaciers covering nearly 144 km². In terms of basin extent, the Bhagirathi-Alaknanda basin covers about 18,718 km², followed by the Yamuna basin (~7,511 km²) and the Ghaghara basin (~5,825 km²).

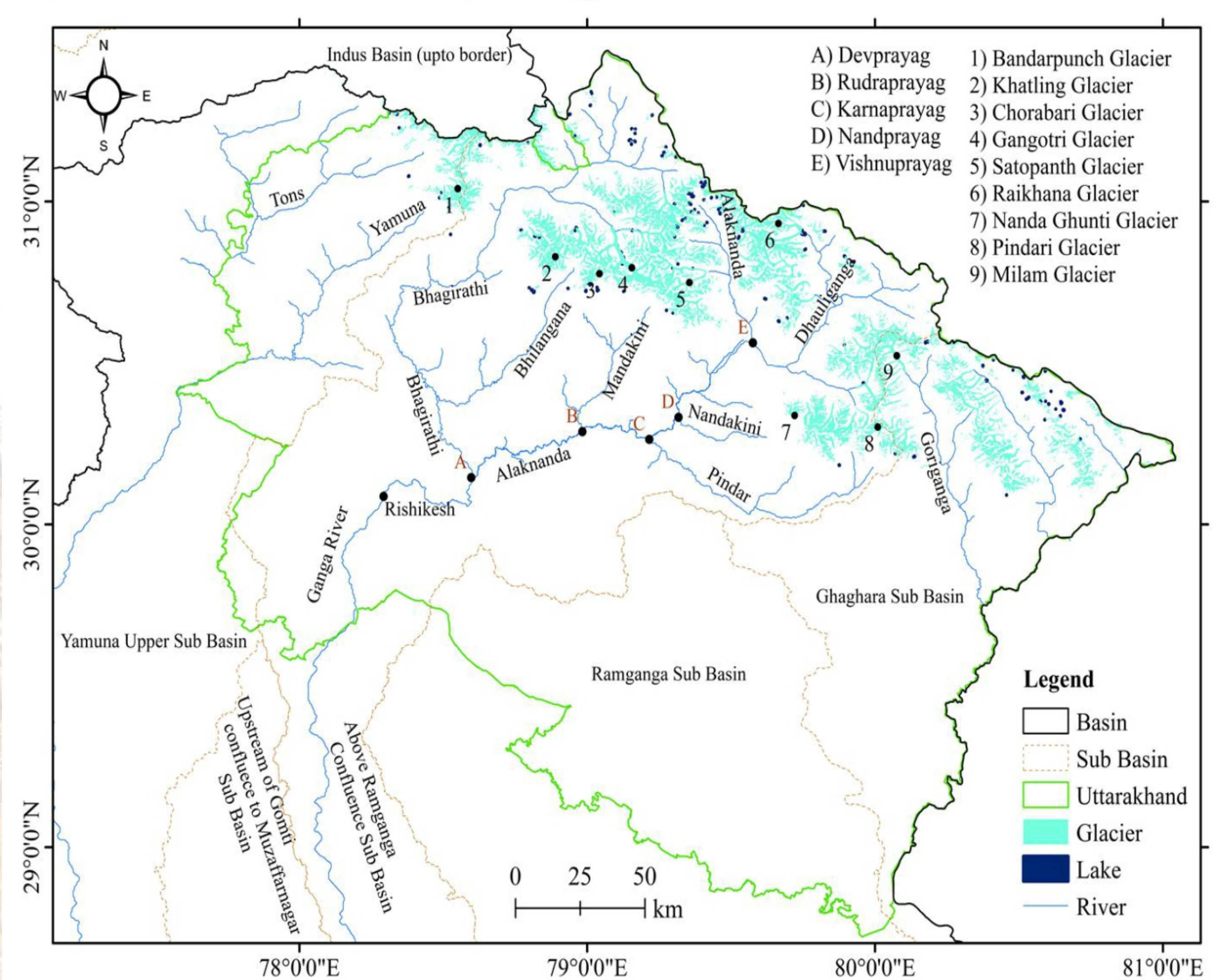
Glaciated area percentages indicate that glaciers occupy roughly 11-12% of the Bhagirathi-Alaknanda and Ghaghara basins, whereas the Yamuna basin has a comparatively smaller glacier cover (~2%). Numerous high-altitude glacial lakes are also present, particularly in the Bhagirathi–Alaknanda basin, which contains 118 lakes, compared to 22 lakes in the Ghaghara basin and 9 lakes in the Yamuna basin.

These glaciers occur across a wide elevation range, extending from about 312 m to 7,801 m above sea level, highlighting the complex topographic and climatic conditions that govern glacier distribution in the Upper Ganga Basin. Valley glaciers dominate the Upper Ganga Basin, including major glaciers such as Gangotri, Satopanth, Pindari and Milam that occupy well-defined mountain valleys.

Key Points:

- Bhagirathi-Alaknanda basin hosts the largest glacier concentration in the Upper Ganga Basin.
- Glacier coverage exceeds 10% in the Bhagirathi-Alaknanda and Ghaghara basins.
- More than 100 glacial lakes occur in the Bhagirathi-Alaknanda basin, indicating active glacier-lake systems.
- Glaciers occur across a wide elevation range (~3,200-7,800 m) reflecting strong altitudinal control on glacier distribution.
- Gangotri and Milam glaciers are among the largest valley glaciers of the Upper Ganga Basin, serving as major sources of the Bhagirathi and Goriganga rivers, respectively.

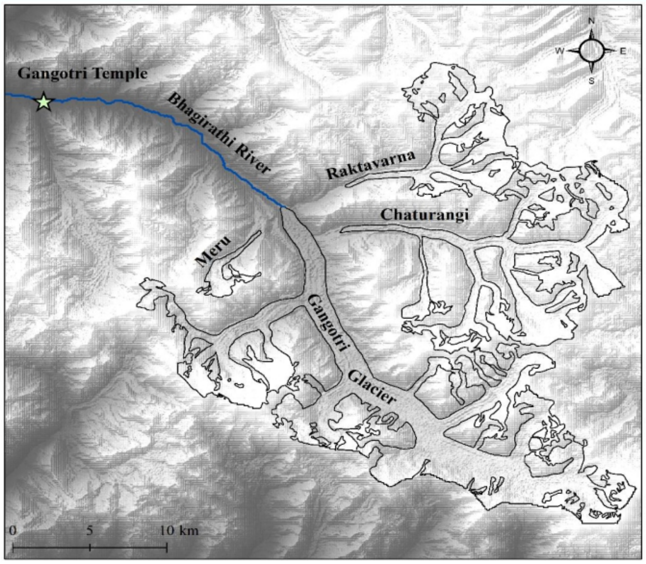
GLACIERS IN THE UPPER GANGA BASIN



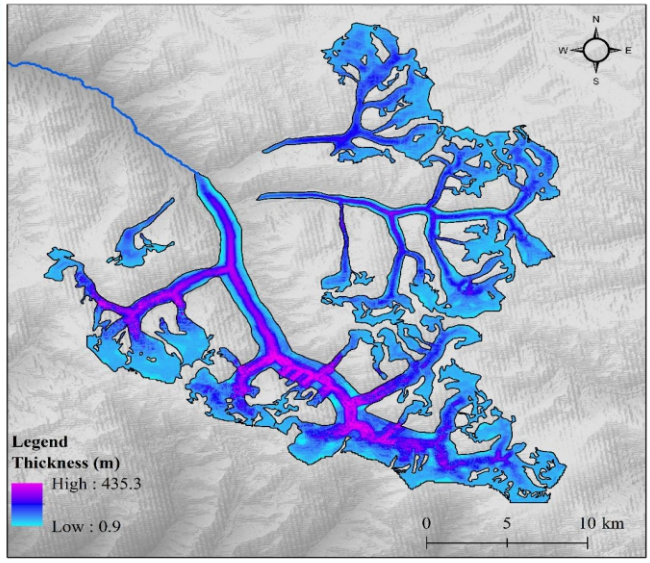
Basin	Bhagirathi & Alaknanda Basin	Yamuna Basin	Ghaghara Basin
No. of Glaciers	645	52	271
Glacier Area (km^2)	1,984	144	729
Basin Area (km^2)	~18,718 (upto Devprayag)	~7,511 (upto Dakpathar)	~5,825 (upto Jauljibi)
Glaciated Area (%)	~11	~2	~12
No. of Lakes	118	9	22
Elevation Range (m)	312-7,801	453-6,271	590-7,320

"Safeguard the glaciers of the Ganga Basin, for they are the first heartbeat of the Ganga"

GANGOTRI GLACIER



Gangotri Glacier Boundary



Gangotri Glacier Thickness

The Gangotri Glacier, located in the Uttarkashi District of Uttarakhand, stands as the largest glacial system in the central Himalayas and the primary source of the Bhagirathi River.

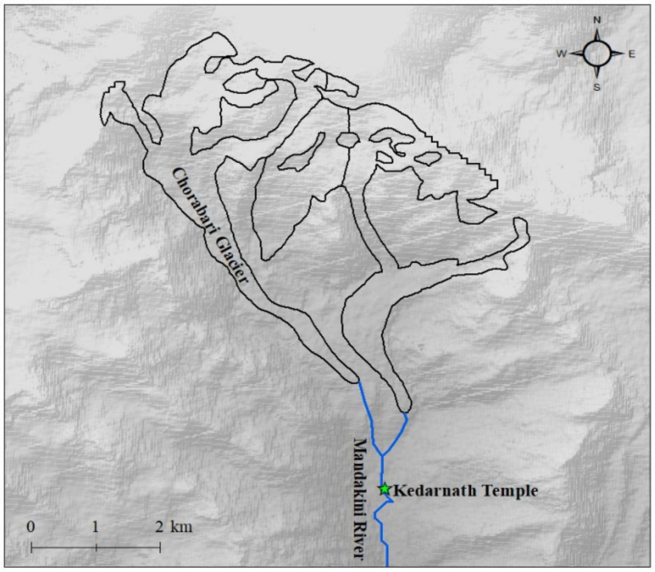
The Gangotri Glacier serves as the perennial headwater for the Bhagirathi River, providing a consistent meltwater base that sustains the hydrological regime of the entire Upper Ganga basin. This massive valley-type glacier extends approximately 30 km in length, with a total main glacier area estimated between 134-140 km². It originates in a high-altitude cirque near the Chaukhamba peaks at an elevation of roughly 7,000 m, descending to its terminus at Gaumukh, situated at approximately 4,100-4,200 m.

The Gangotri Glacier system is fed by major tributary glaciers such as the Chaturangi (63.07 km^2), Raktvarna (30.46 km^2), and Meru (4.29 km^2). Scientific monitoring, including recent studies confirmed that the glacier has been in a state of continuous retreat since 1950. The Gangotri Glacier receded by approximately 20 m yr^{-1} between 1935 and 2022.

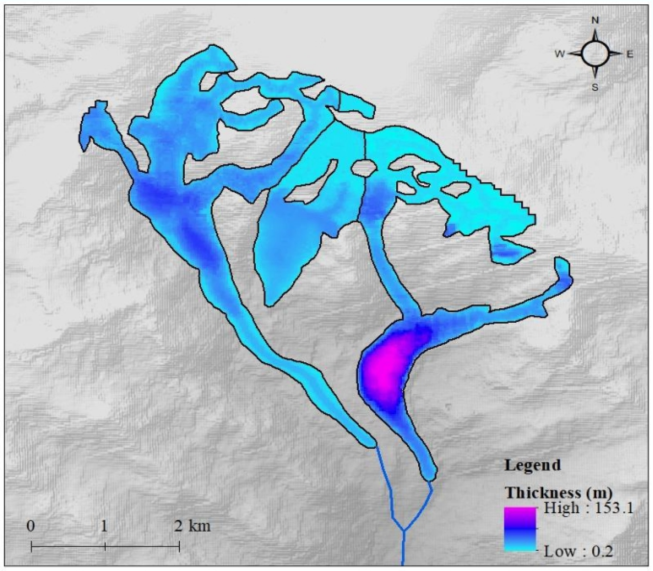
Key Features of the Gangotri Glacier

Parameters	Description
Type	Valley Glacier
Location	30° 47' 43.44" N, 79° 09' 18.71" E
Approximate Length (km)	~30
Approximate Main Glacier Area (km^2)	~134
Mean Glaciation level (m)	~5,120
Terminus Elevation (m)	~4,085

CHORABARI GLACIER



Chorabari Glacier Boundary



Chorabari Glacier Thickness

The Chorabari Glacier, located in the Rudraprayag District of Uttarakhand, is a medium-sized compound valley-type glacier but hydrologically significant glacier in the central Himalayas. It lies in close proximity to the sacred pilgrimage site of Kedarnath Temple and forms an important source of the Mandakini River.

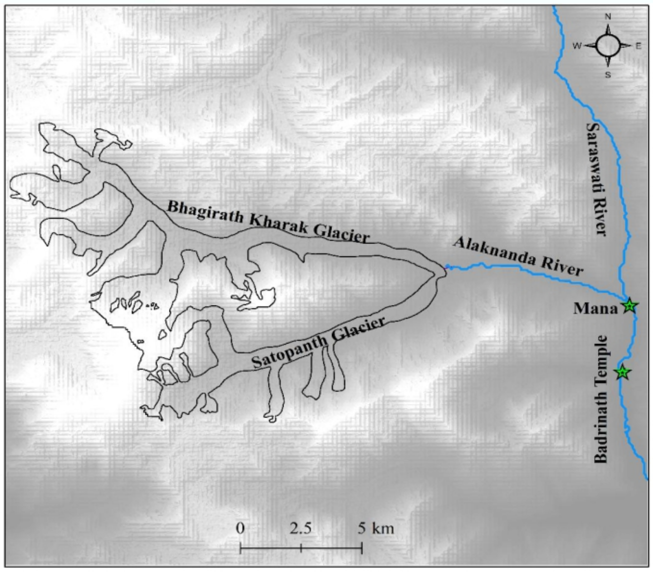
The Chorabari Glacier acts as a perennial source of meltwater for the Mandakini River. This valley-type glacier extends approximately 6-7 km in length, with a glacierized area of 6-7 km². The glacier originates from the high-altitude snowfields and cirques surrounding Kedarnath Peak and Kedar Dome, at elevations exceeding 6,500 m, and descends to its snout near Chorabari Tal at an elevation of approximately 3,800-3,900 m above sea level.

Changes in the glacier and the associated Chorabari Tal have also been linked to hydrological hazards, including the catastrophic flood event in the Mandakini valley during the 2013 Kedarnath floods. Long-term average retreat rate of the Chorabari Glacier has increased significantly from 6.4 (1962-2003) to 9.3 m yr^{-1} (2003-10).

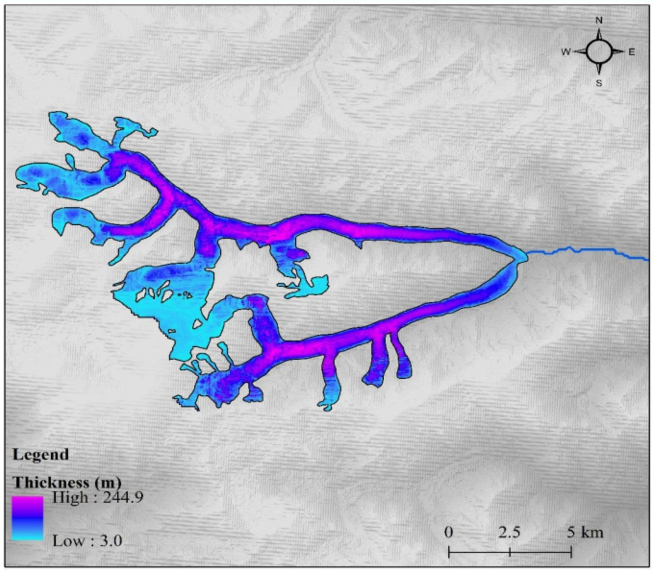
Key Features of the Chorabari Glacier

Parameters	Description
Type	Valley Glacier
Location	30° 46' 37.20" N, 79° 02' 34.08" E
Approximate Length (km)	~6.9
Approximate Main Glacier Area (km²)	~6.3
Mean Glaciation level (m)	~ 5,190
Terminus Elevation (m)	~3,851

SATOPANTH GLACIER



Satopanth Glacier Boundary



Satopanth Glacier Thickness

The Satopanth Gglacier, located in the Chamoli District of Uttarakhand, represents one of the major glacier systems in the central Himalayas and forms an important headwater source of the Alaknanda River. The glacier system is closely associated with the nearby Bhagirathi-Kharak Glacier.

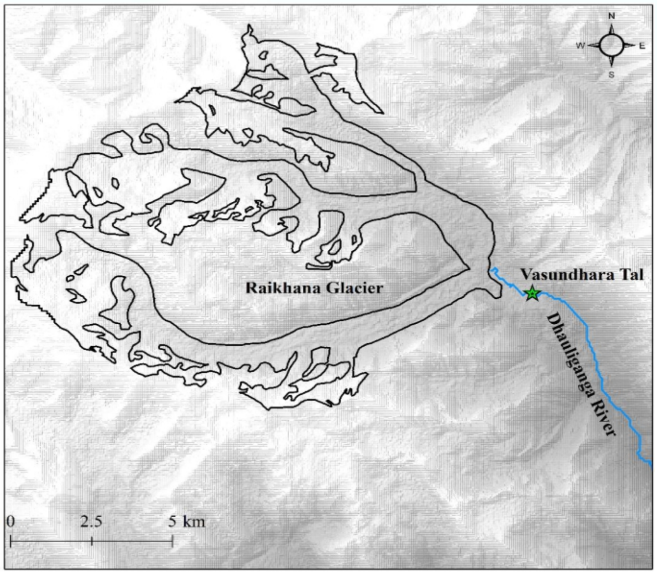
The Satopanth Glacier functions as a perennial source of meltwater that contributes significantly to the hydrological regime of the upper Alaknanda basin. This valley-type glacier extends approximately 13-14 km in length, with a total glacierized area of 19-20 km². The glacier originates from the high-altitude cirques and snowfields surrounding the Chaukhamba Peak at elevation exceeding 6,500 m, and descends to its snout near Mana village at an elevation of approximately 3,900-4,000 m above sea level. The glacier is located close to the sacred pilgrimage site of Badrinath Temple, which lies downstream along the Alaknanda River.

The Satopanth Glacier showed an average retreat rate of approximately 4.8 m yr^{-1}, while the Bhagirathi-Kharak Glacier exhibited an average retreat rate of approximately 3.7 m yr^{-1} during the period 1968-2017.

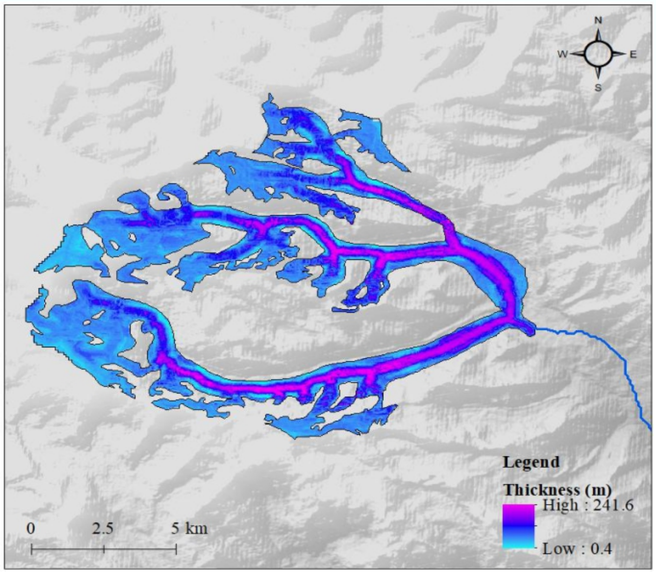
Key Features of the Satopanth Glacier

Parameters	Description
Type	Valley Glacier
Location	30° 44' 57.84" N, 79° 21' 19.44" E
Approximate Length (km)	~13
Approximate Main Glacier Area (km²)	~19
Mean Glaciation level (m)	~ 4,950
Terminus Elevation (m)	~3,918

RAIKHANA GLACIER



Raikhana Glacier Boundary



Raikhana Glacier Thickness

The Raikhana (or Raykana) Glacier, located in the Chamoli District of Uttarakhand, is an important glacier in the upper Dhauliganga River basin of the central Himalaya. The glacier contributes meltwater to the Dhauliganga River, which eventually joins the Alaknanda River. The glacier lies in the high-altitude region near Vasudhara Tal, a glacial lake situated close to the Indo-Tibetan border.

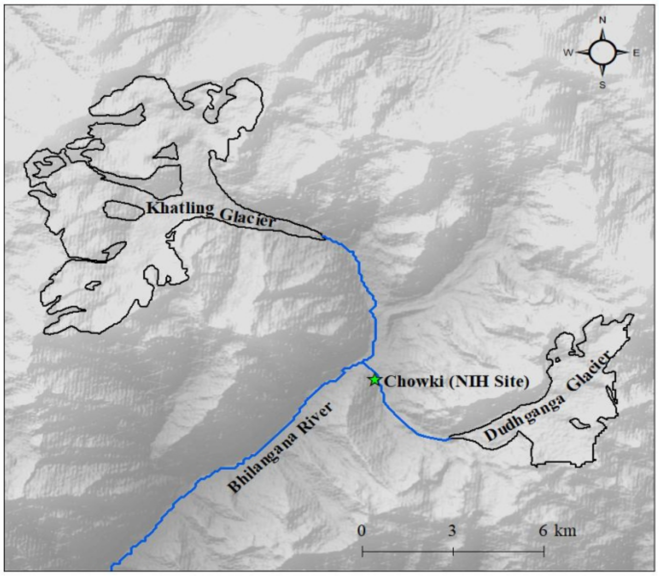
The Raikhana Glacier functions as a perennial source of meltwater that helps sustain the hydrological regime of the upper Dhauliganga basin. This valley-type glacier extends approximately 17–18 km in length, with an estimated glacierized area of 58-60 km². The glacier originates from high-altitude accumulation zones of the Kamet peak at elevation exceeding 7,000 m above sea level, and descends to its snout at an elevation of approximately 4,600-4,800 m.

The Raikhana Glacier has showed noticeable retreat in recent decades, with an average retreat rate of approximately 7.19 m yr^{-1} during the period 1968-2016.

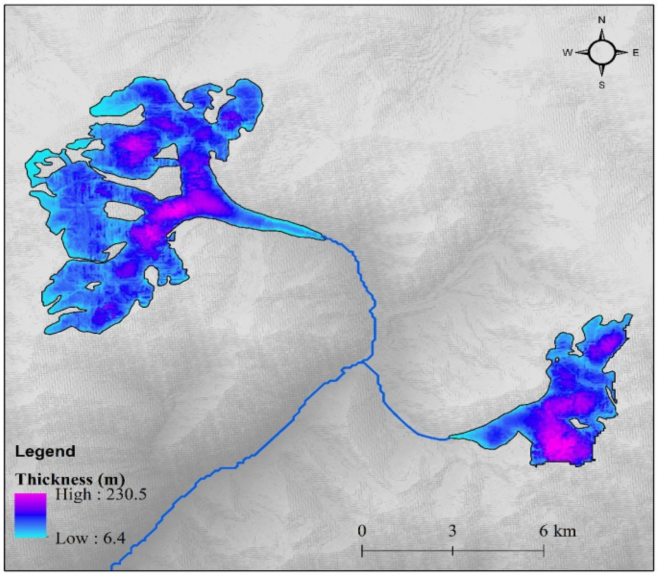
Key Features of the Raikhana Glacier

Parameters	Description
Type	Valley Glacier
Location	30° 55' 56.64" N, 79° 39' 52.93" E
Approximate Length (km)	~17
Approximate Main Glacier Area (km²)	~59
Mean Glaciation level (m)	~ 5,230
Terminus Elevation (m)	~4,720

KHATLING GLACIER



Khatling Glacier Boundary



Khatling Glacier Thickness

The Khatling Glacier, located in the Tehri Garhwal District of Uttarakhand, is one of the prominent glaciers of the central Himalayas. It lies in the upper catchment of the Bhilangana River, which later joins the Bhagirathi River. The glacier system is also associated with the nearby Dudhganga Glacier.

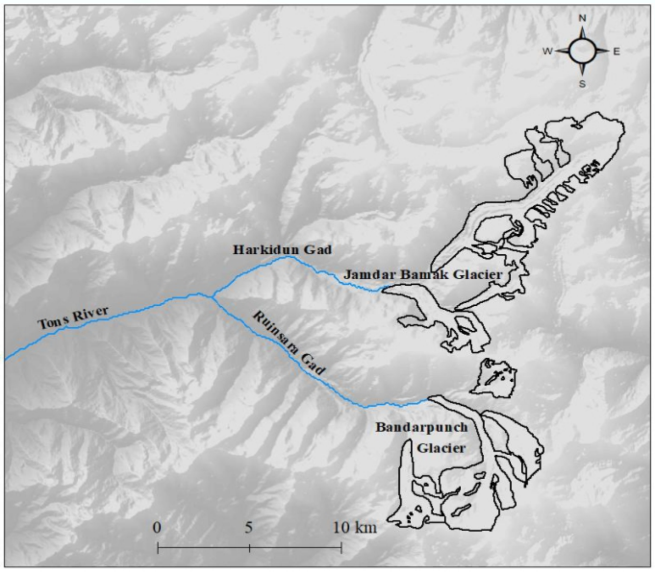
The Khatling and Dudhganga glacier serves as a perennial source of meltwater for the Bhilangana River, contributing significantly to the hydrological regime of the Bhagirathi basin. This valley-type glacier extends approximately 10-11 km in length, with a glacierized area of about 31-32 km². The glacier originates from high-altitude accumulation zones near the Jogin Peak at elevation exceeding 6,300 m above sea level, and descends to its snout at an elevation of roughly 4,000-4,100 m.

The total recession of Khatling Glacier measured along the central flow line of the glacier showed that the glacier snout receded between 1965 to 2014 is 31 m yr^{-1}. Most of the debris-covered glaciers in this valley exhibited a significant rate of retreat in the last two decades.

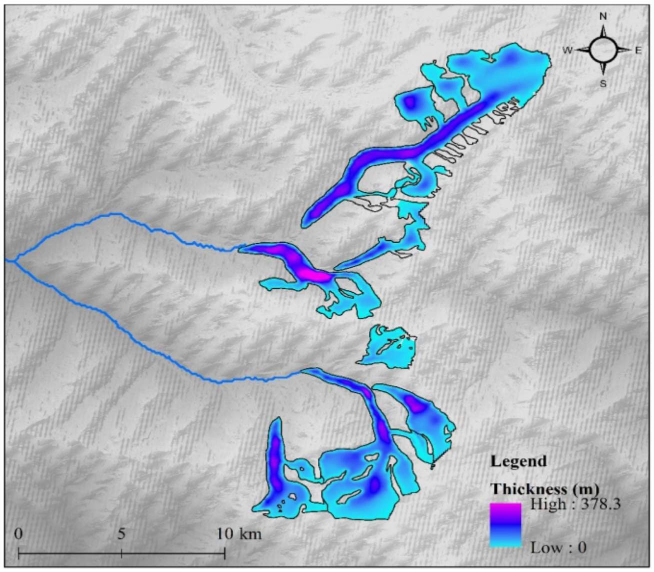
Key Features of the Khatling Glacier

Parameters	Description
Type	Valley Glacier
Location	30° 49' 45.12" N, 78° 53' 22.93" E
Approximate Length (km)	~10
Approximate Main Glacier Area (km²)	~32
Mean Glaciation level (m)	~ 5,070
Terminus Elevation (m)	~4,082 m

BANDARPUNCH GLACIER



Bandarpunch Glacier Boundary



Bandarpunch Glacier Thickness

The Bandarpunch Glacier, located in the Uttarkashi District of Uttarakhand, is one of the important glaciers of the central Himalayas. It lies in the upper catchment of the Yamuna River basin and forms a significant source of the Tons River.

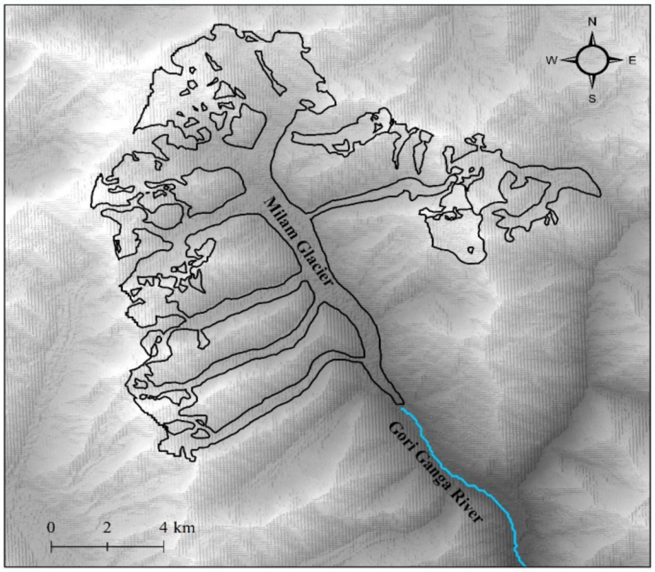
The Bandarpunch Glacier functions as a perennial source of meltwater that contributes to the hydrological regime of the upper Yamuna basin. This valley-type glacier extends approximately 12-13 km in length, with a glacierized area of about 29-30 km². The glacier originates from the high-altitude snowfields and cirques surrounding the Bandarpunch Peak at elevations exceeding 6,200 m above sea level, and descends to its terminus at an elevation of approximately 3,700-3,800 m.

The Bandarpunch Glacier has exhibited significant retreat over the past several decades. Scientific monitoring and recent studies confirm that the glacier has been in a state of continuous recession. Observations indicate that the glacier retreated at an average rate of approximately 25.5 m yr^{-1} between 1960 and 1999.

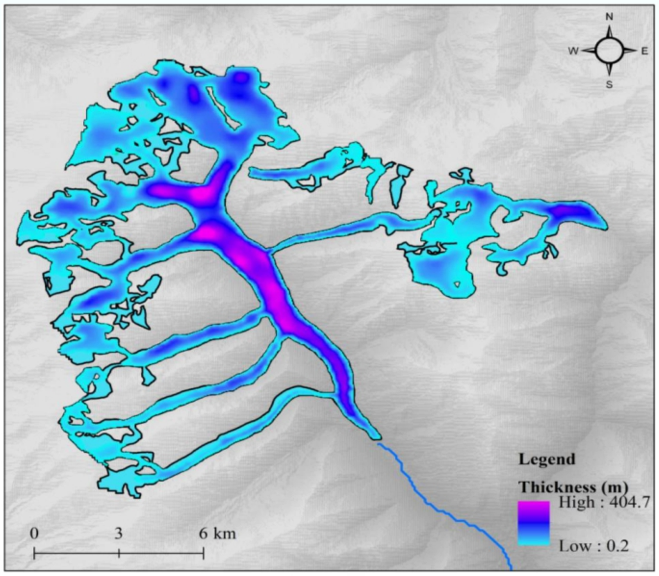
Key Features of the Bandarpunch Glacier

Parameters	Description
Type	Valley Glacier
Location	31° 02' 24.00" N, 78° 33' 03.61" E
Approximate Length (km)	~13
Approximate Main Glacier Area (km^2)	~30
Mean Glaciation level (m)	~ 5,230
Terminus Elevation (m)	~3,750

MILAM GLACIER



Milam Glacier Boundary



Milam Glacier Thickness

The Milam Glacier is located in the Munsiyari Valley in the Pithoragarh district of Uttarakhand. It is one of the largest glaciers of the Kumaon Himalaya and lies in the upper catchment of the Gori Ganga River, which later joins the Kali River along the Indo-Nepal border.

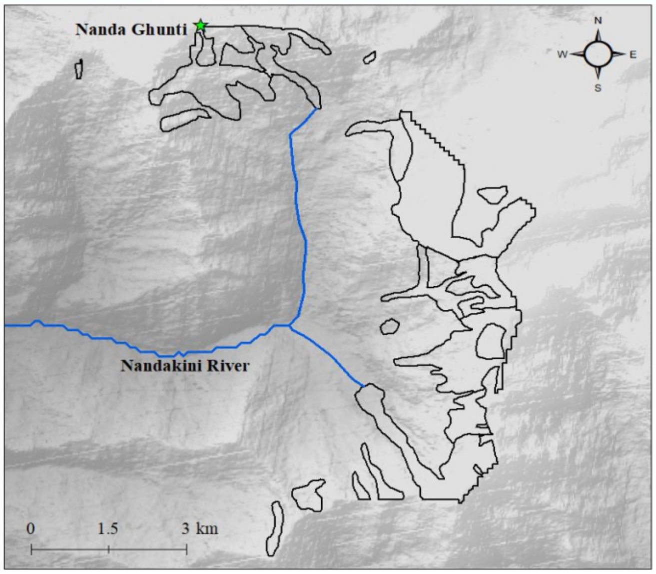
The Milam Glacier serves as a perennial source of meltwater for the Gori Ganga River and plays a significant role in sustaining the hydrological regime of the eastern Himalayan river systems. This valley-type glacier extends approximately 15-16 km in length, with a glacierized area of about 55-60 km^2. The glacier originates from high-altitude snowfields and cirques at elevations exceeding 6,500 m above sea level, and descends to its snout at an elevation of around 3,600-3,700 m, forming an extensive glacial valley system.

Long-term observations indicate that the Milam Glacier has experienced significant retreat over the past several decades. During the last 70 years, the Milam Glacier has showed an average recession rate of approximately 20.90 m yr^{-1}.

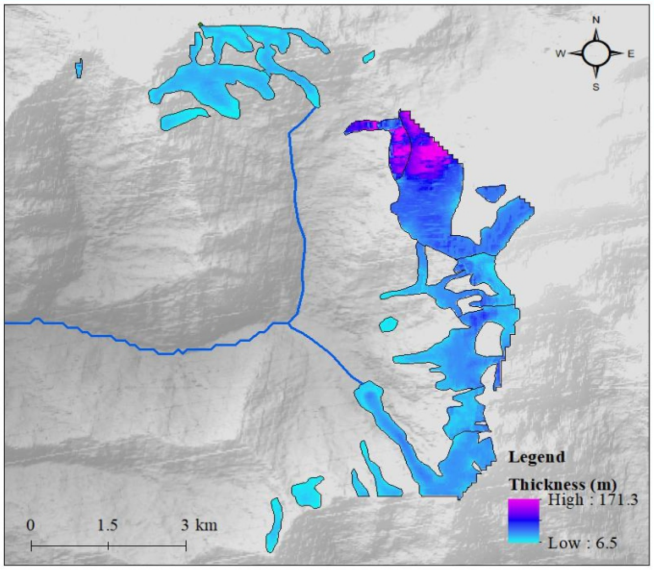
Key Features of the Milam Glacier

Parameters	Description
Type	Valley Glacier
Location	30° 31' 22.08" N , 80° 04' 33.23" E
Approximate Length (km)	~16
Approximate Main Glacier Area (km^2)	~59
Mean Glaciation level (m)	~5,145
Terminus Elevation (m)	~3,695

NANDA GHUNTI GLACIER



Nanda Ghunti Glacier



Nanda Ghunti Glacier Thickness

The Nanda Ghunti Glacier, located in the Chamoli District of Uttarakhand, is an important glacier of the central Himalayas. The glacier lies in the vicinity of the Nanda Ghunti Peak and contributes meltwater to tributaries that eventually drain into the Alaknanda River.

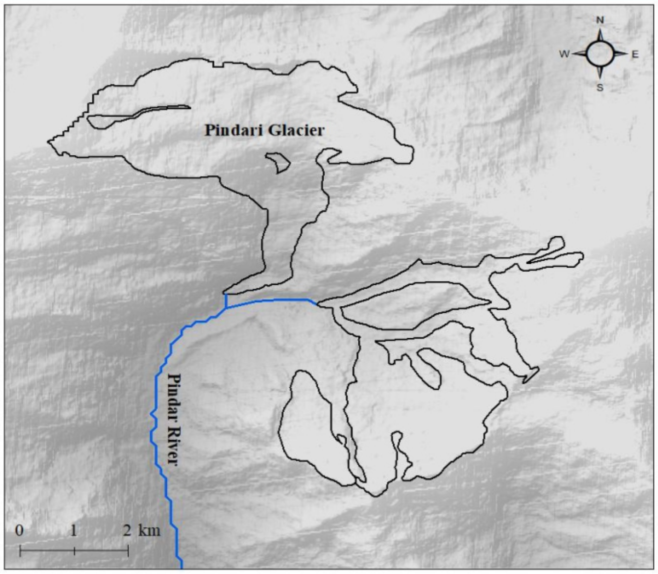
The Nanda Ghunti Glacier acts as a perennial source of meltwater that supports the hydrological regime of the upper Alaknanda basin. This hanging-type glacier extends approximately 2-3 km in length, with a glacierized area estimated to be around 2-3 km². The glacier originates from the high-altitude snowfields and cirques surrounding Nanda Ghunti Peak, at elevations exceeding 6,300 m above sea level, and descends to its terminus at an elevation of approximately 4,600-4,700 m.

Limited scientific monitoring and available studies suggest that the Nanda Ghunti Glacier has been experiencing a gradual and continuous retreat over the past several decades, with an estimated average retreat rate of approximately 8–10 m yr^{-1}.

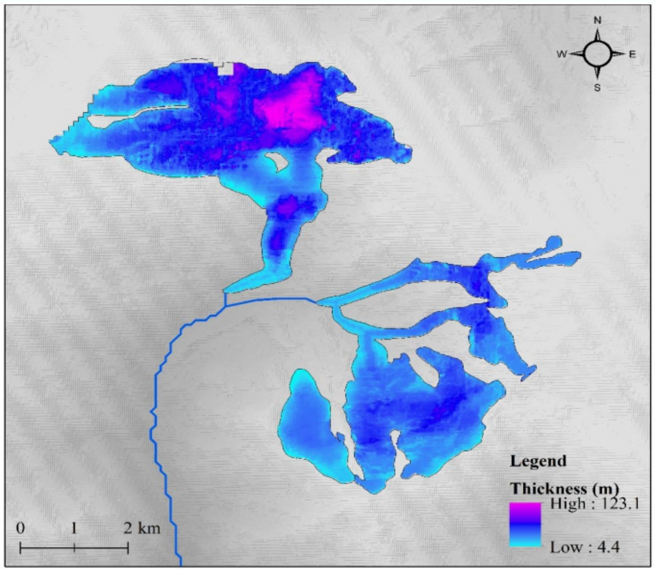
Key Features of the Nanda Ghunti Glacier

Parameters	Description
Type	Hanging Glacier
Location	30° 20' 15.00" N, 79° 43' 15.60" E
Approximate Length (km)	~2
Approximate Main Glacier Area (km²)	~2
Mean Glaciation level (m)	~ 5,400
Terminus Elevation (m)	~4,650

PINDARI GLACIER



Pindari Glacier Boundary



Pindari Glacier Thickness

The Pindari Glacier, located in the Bageshwar District of Uttarakhand, is one of the well-known glaciers of the Kumaon Himalaya. It lies in the upper catchment of the Pindar River, which later joins the Alaknanda River, an important headstream of the Ganga River.

The Pindari Glacier serves as a perennial source of meltwater for the Pindar River and contributes significantly to the hydrological regime of the upper Alaknanda basin. This valley-type glacier extends approximately 4-5 km in length, with a glacierized area of about 11-12 km². The glacier originates from the high-altitude snowfields and cirques surrounding prominent Himalayan peaks such as Nanda Devi East and Nanda Kot, at elevations exceeding 6,400 m above sea level, and descends to its snout near Zero Point (Pindari Glacier snout) at an elevation of approximately 3,900-4,000 m.

The Pindari Glacier, located in the Alaknanda Basin, showed an average retreat rate of about 9.4 m yr^{-1} during the period 1958-2001.

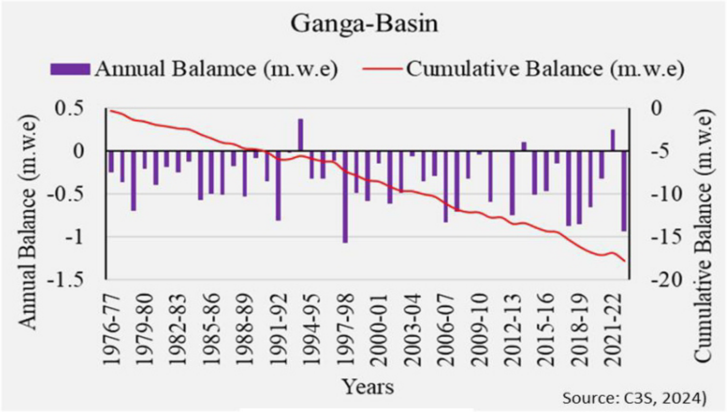
Key Features of the Pindari Glacier

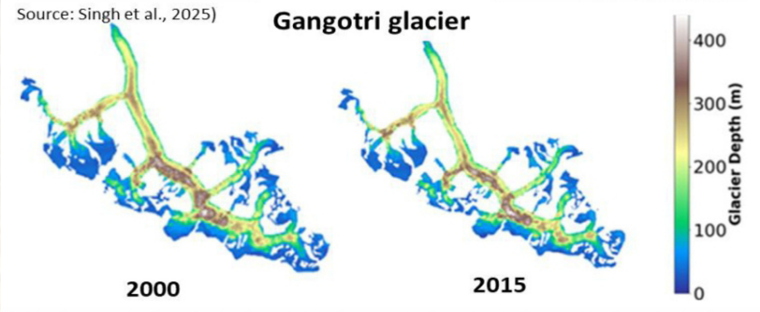
Parameters	Description
Type	Valley Glacier
Location	30° 18' 06.12" N, 80° 00' 35.65" E
Approximate Length (km)	~4
Approximate Main Glacier Area (km²)	~11
Mean Glaciation level (m)	~ 5,350
Terminus Elevation (m)	~3,982

GLACIER CHANGES & EMERGING CHALLENGES

Glaciers of the Upper Ganga Basin are undergoing significant changes due to rising temperatures and changing precipitation patterns. Observations from satellite imagery and field studies indicate widespread glacier retreat and negative mass balance over recent decades. These changes are altering meltwater contributions to river systems and influencing the hydrological regime of the basin.

Observed Glacier Changes





- Most Himalayan UGB glaciers show retreat trends since the late 20th century.
- Highlight that major glaciers in the Upper Ganga (Bhagirathi and Alaknanda basins) are retreating at an average rate of ~15 m yr^{-1} (C3S, 2024).
- Many glaciers exhibit negative mass balance, indicating loss of ice volume.
- Increasing debris cover and fragmentation observed in several glaciers.
- Gangotri Glacier has retreated significantly over the past century Singh et al. 2025).

Implications and Emerging Challenges

- Increased glacier melt contribution during summer months and potential short-term increase in meltwater runoff.
- Long-term risk of declining water availability as glaciers shrink and changes in seasonal flow patterns of the Ganga headwaters.
- Formation and expansion of glacial lakes due to glacier retreat which could increase the risk of Glacial Lake Outburst Floods (GLOFs).
- Sediment transport and slope instability in de-glaciated areas.
- Need for continuous monitoring and early warning systems.

GLACIER MONITORING & SCIENTIFIC OBSERVATIONS

Continuous monitoring of Himalayan glaciers is essential to understand their response to climate variability and long-term environmental change. Scientific observations provide valuable insights into glacier dynamics, mass balance, and meltwater contribution to river systems. Glacier monitoring combines field measurements, satellite observations, and hydrological studies to track changes in glacier extent and behaviour.

Field-Based Observations

- Mass balance measurements using stakes and snow pits.
- Monitoring of snow accumulation and ice melt rates.
- GPS and ground surveys to track glacier movement and terminus changes.
- Installation of Automatic Weather Stations (AWS) and discharge monitoring sensors near glaciers.

Remote Sensing and Satellite Monitoring

- Mapping glacier area and length changes using satellite imagery and Aerial surveys.
- Use of multi-temporal datasets (Landsat, Sentinel, Resourcesat).
- Monitoring glacial lakes and debris-covered glaciers.
- Generation of Digital Elevation Models (DEMs) to assess glacier volume change.

Hydrological Modeling

- Estimation of glacier melt contribution to river discharge using field observations and hydrological modelling viz. SWAT, SPHY, VIC models etc.
- Monitoring of snow cover and seasonal melt dynamics through satellite data and ground measurements and its integration in Hydrological Models.
- Hydrological modeling for glacier mass changes and assessment of future meltwater contribution under climate variability using climate models.

Field Measurements on Glacier Sites

GLACIER LINKAGES WITH LIFE OF COMMON MAN

Although glaciers exist in high mountain regions, their influence extends far downstream. Glacier meltwater contributes to the flow of major rivers in the Ganga basin, supporting drinking water supply, agriculture, hydropower generation and ecosystem services. Changes in glacier mass balance can therefore directly impact the livelihoods of millions of people.

- **Drinking Water**

Glacier-fed rivers originating in the Himalayas play a vital role in providing freshwater to a large population across South Asia. It is estimated that nearly 800 million people depend on water from the Himalayan river systems, including the Ganga River, Brahmaputra River, and Indus River. Glacier and snow melt act as natural reservoirs that release water gradually, especially during the dry summer months when rainfall is limited. This meltwater sustains the base flow of major rivers and ensures the continuous availability of freshwater for drinking and domestic use in many mountain and downstream regions.

Image Credit: Dr. Atar Singh, NIH

- **Agriculture**

Image Source: google open access

Agriculture in the Indo-Gangetic Plain relies heavily on water from glacier-fed rivers originating in the Himalayas. The Ganga River basin alone supports nearly 40 percent of India's population and a large share of the country's irrigated agriculture. Meltwater from Himalayan glaciers contributes significantly to river discharge, particularly during the dry season when rainfall is limited. Therefore, any changes in glacier melt contribution due to climate change can directly influence irrigation availability and crop productivity across the basin.

- **Hydropower**

The Himalayan region possesses significant hydropower potential due to its steep topography and the presence of numerous glacier-fed rivers. In India, the Himalayan river systems contribute substantially to the country's hydropower generation, with an estimated potential of more than 145 GW. In particular, Uttarakhand is one of the most important

Image Source: google open access

hydropower-producing states in the Indian Himalaya because major rivers such as the Ganga River, Alaknanda River, Bhagirathi River, Yamuna River, and Tons River originate from glacierized catchments and support several hydropower projects. Some of the major hydropower projects in Uttarakhand include the Tehri Dam, the Vishnuprayag Hydroelectric Project, Tapovan-Vishnugad Hydroelectric Project and the Maneri Bhali Hydroelectric Project.

- **Ecosystems**

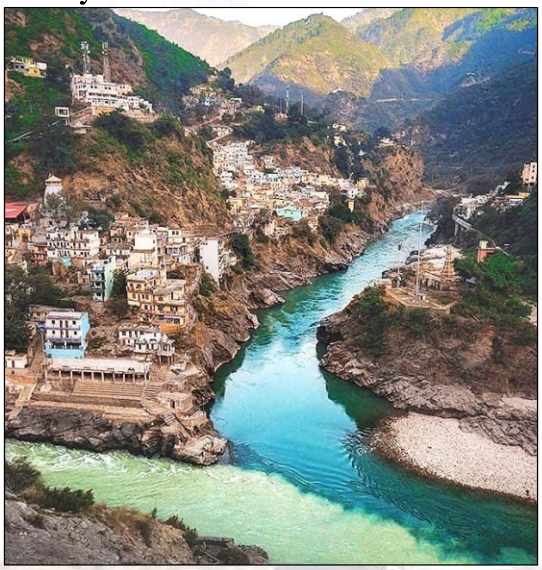


Image Source: google open access

Glaciers play a fundamental role in sustaining the ecosystems of the Himalayan region by regulating river flow, water temperature, and sediment transport. In addition, sediments carried by glacial meltwater help shape river channels, maintain floodplains, and provide nutrients that support riparian vegetation and high-altitude ecosystems. However, the ongoing retreat of Himalayan glaciers due to climate change is altering these natural processes. Furthermore, glacier retreat may cause upward shifts in alpine vegetation zones, placing stress on high-altitude plant and animal species that depend on cold climatic conditions. In addition, the natural landscapes and biodiversity of glacier-fed valleys support tourism and cultural traditions, which are important sources of livelihood for Himalayan communities. Therefore, the health of glacier systems and Himalayan ecosystems is directly connected to the socio-economic well-being and environmental sustainability of millions of people.

- **Hazards**

Glacier retreat often leads to the formation and expansion of glacial lakes as melting ice accumulates behind unstable moraine or ice dams. The Himalayas currently contain more than 15,000 glacial lakes, many of which are considered potentially dangerous due to the possibility of sudden dam failure. Such failures can trigger Glacial Lake Outburst Floods (GLOFs), which release large volumes of water and debris downstream, causing severe damage to infrastructure, settlements, and agricultural land. In India, the 2013 Chorabari Lake breach in Uttarakhand triggered catastrophic flooding in the Kedarnath and Mandakini valleys.

Image Credit: Dr. Atar Singh, NIH

"Understanding glaciers today prevents disasters downstream tomorrow"

STRENGTHENING GLACIER MONITORING, RESEARCH & WAY FORWARD

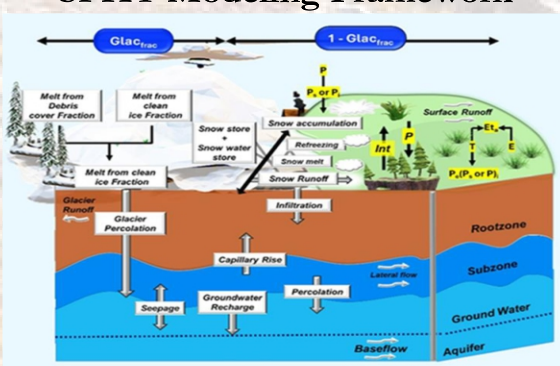
Continuous monitoring of Himalayan glaciers is essential for understanding their response to climate variability and for assessing future water availability in the Ganga basin. Strengthening scientific observations through field measurements, satellite monitoring, and hydrological modelling will help improve glacier research and support better hazard assessment and water resource planning.

Strengthening Glacier Monitoring

- Expansion of long-term glacier monitoring sites for mass balance and glacier dynamics.
- Installation of automatic weather stations and stake networks on key glaciers.
- Regular mapping of glacier area and terminus changes using satellite imagery.
- Monitoring of snow cover, glacier lakes, and debris-covered glaciers.

Image Credit: Dr. Akshaya Verma, NIH

SPHY Modeling Framework



Advancing Scientific Research

- Integration of remote sensing and field observations for glacier change assessment.
- Development of hydrological and glacier mass balance models.
- Improved understanding of glacier–river interactions and meltwater contribution.
- Study of debris cover influence and glacier dynamics.

Way Forward

- Establish integrated glacier monitoring networks across the Upper Ganga Basin.
- Strengthen glacial lake monitoring and early warning systems for GLOFs.
- Promote collaboration among scientific institutions and agencies.
- Support long-term cryosphere research for climate adaptation and water security.

"Protect the snow, preserve the glaciers, and secure the water of tomorrow"

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In the frozen heights of the Himalaya begins the life of the Ganga, a journey shaped by melting ice and time itself.

Guard the glaciers today, so the river of life continues tomorrow.

Image: Dokriani Glacier, Garhwal Himalayas; Credit: Dr. Akshaya Verma, NIH

In silent peaks where glaciers stay,
The Ganga finds its timeless way.
If we protect this frozen art,
We safeguard life in every part.

सत्यमेव जयते

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Ministry of Jal Shakti, Government of India