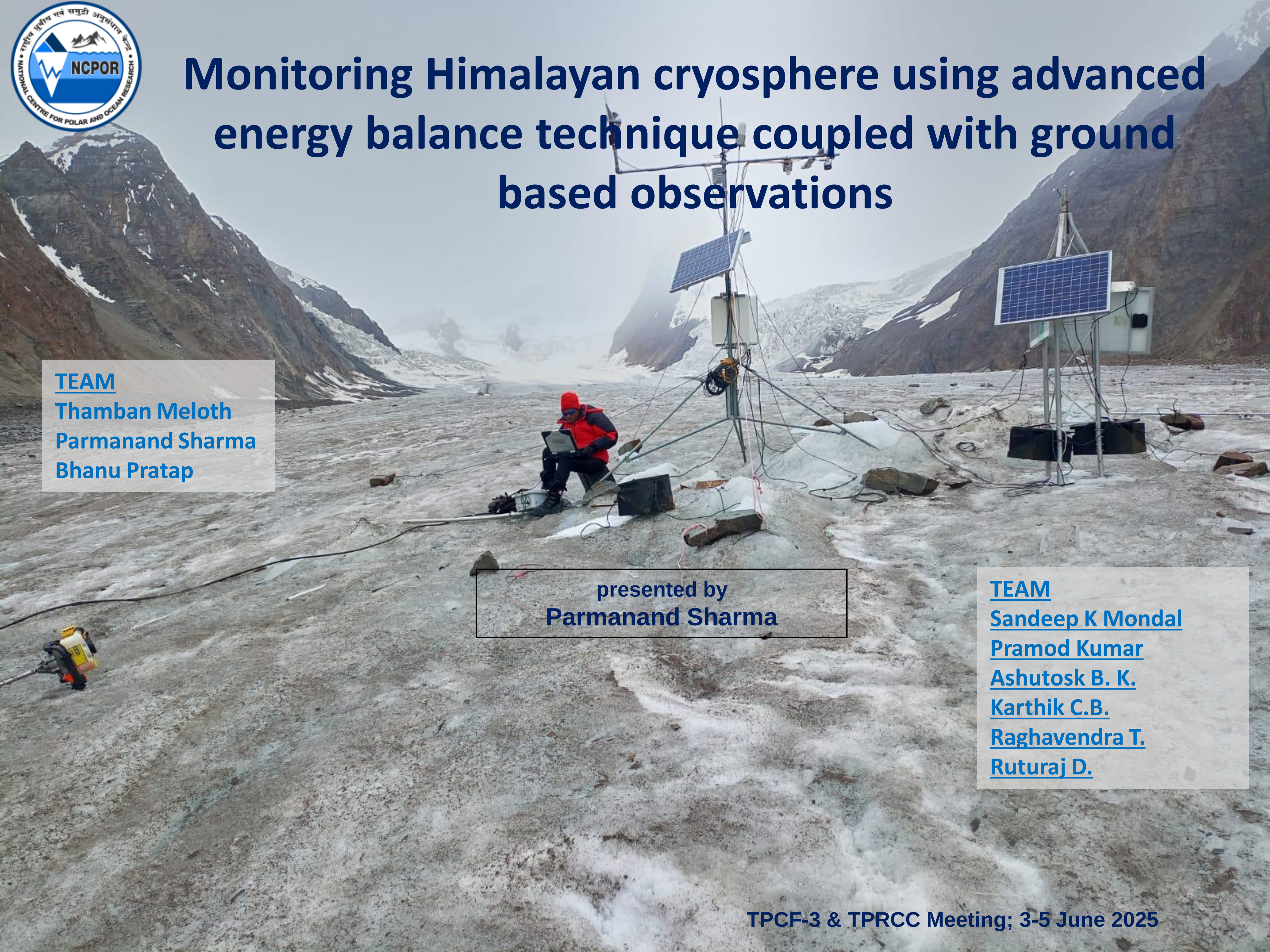


Monitoring Himalayan cryosphere using advanced energy balance technique coupled with ground based observations

TEAM
Thamban Meloth
Parmanand Sharma
Bhanu Pratap

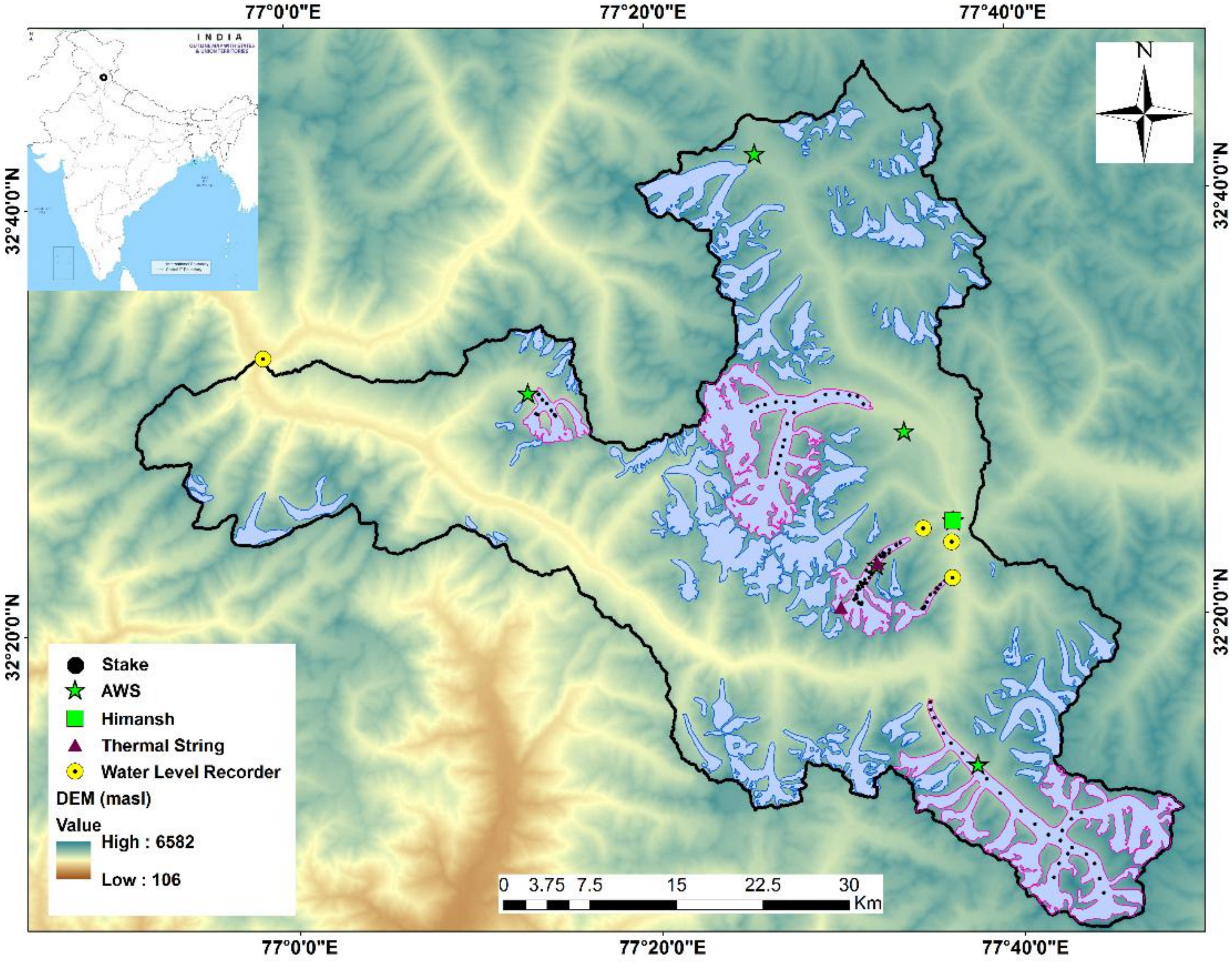
presented by
Parmanand Sharma

TEAM
Sandeep K Mondal
Pramod Kumar
Ashutosk B. K.
Karthik C.B.
Raghavendra T.
Ruturaj D.

TPCF-3 & TPRCC Meeting; 3-5 June 2025

Study Area-Chandra Baisn

Chandra basin



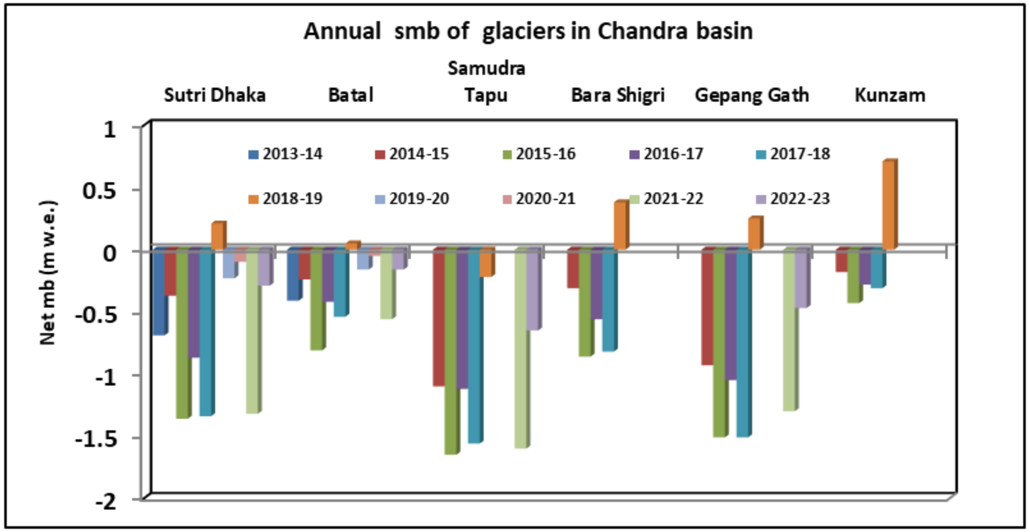
Total Catchment Area : 2446 km²

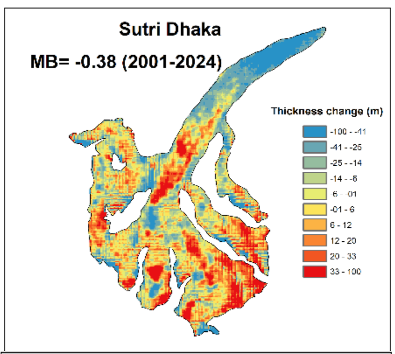
Total Glacier Area: >650km² (26%)

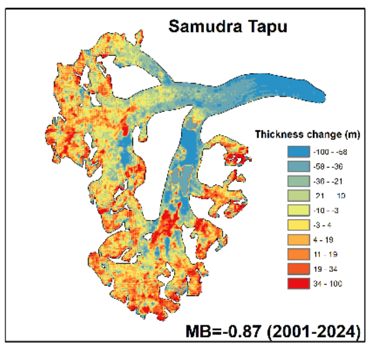
Monitoring seven glaciers >200km² (32%)

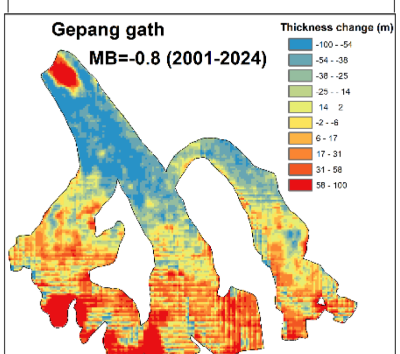
Only five glaciers having more than 20km² area

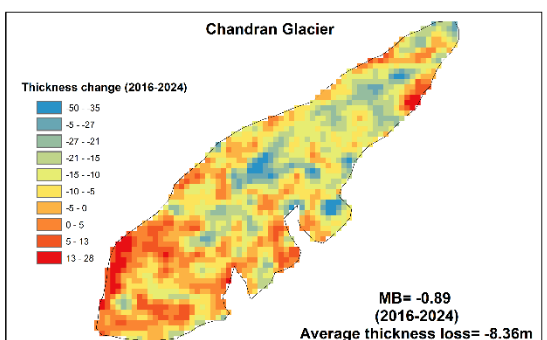
Glacier Mass balance in Chandra basin during 2013-2023





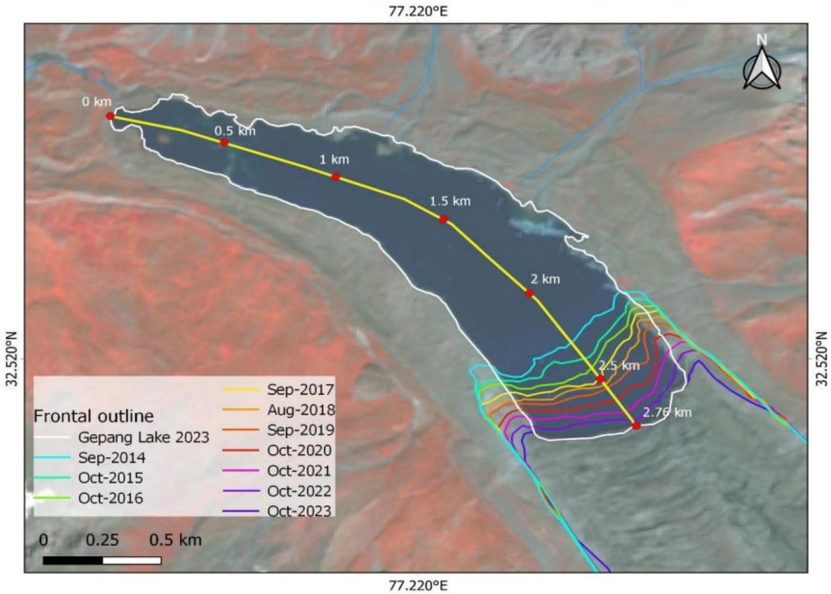


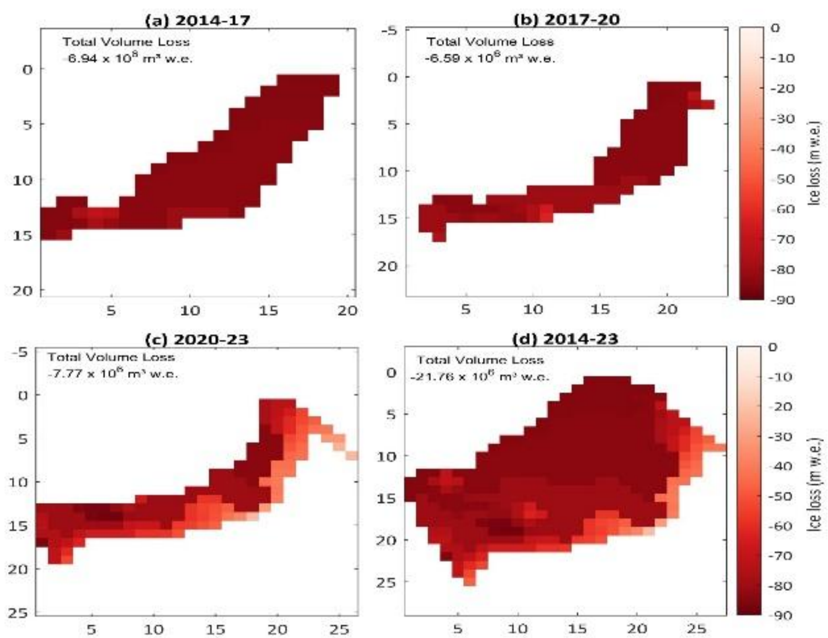




- Annual mass loss/gain -1.65 to 0.71m w.e
- Mean annual mass loss: -0.59m w.e a^{-1}
- Lost 4 GT(Giga ton) of glacier mass
- Mean thinning of 4 m during last 10 years
- Lost approximately 6-7% of glacierized area
- Samudra Tapu experienced hightest negative balance among all studies glaciers
- Comparative less negative balance in 2022 -2023 than 2021-22
- Heavy snow during late spring and monsoon

Mass loss of lake terminating Gepang Gath glacier





❖Significant change in length (ranges 14m/y to 53m/y)

❖Frontal width changes (760m to 940m)

❖Glacier has retreated 480 m during 2014-2023 and lost area of 0.40 km^2

❖Annual ablation -0.9±0.12 m w.e. Lost more than 7 m thick ice during last 8 years

❖Frontal ice loss increased net annual ablation by 17% and negative balance by 22%.

❖Overall, calving front increased ice loss by 15-25% during 2014-2023

Pratap et al, 2024

Mass loss of lake terminating Gepang Gath glacier

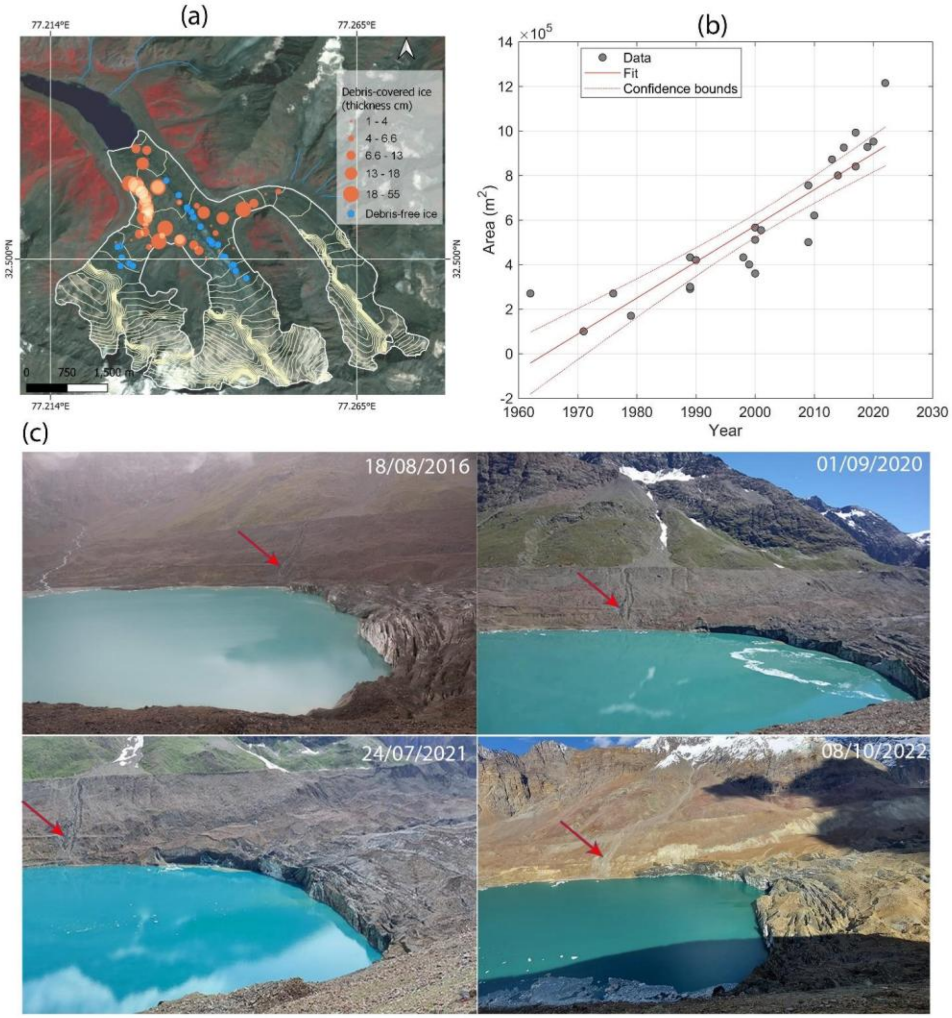


Fig: a) Blue dots represent the debris-free ice area, the orange colour dots shows debris area with thickness , b) The time series expansion of proglacial lake during 1962 to 2023, c) Field observations of the calving front and pro-glacial lake of the Gepang Gath Glacier.

Lake expansion during 1979-2017 : 0.17 km^2 to 0.84 km^2
Lake expansion from 2017-2023: 0.84 km^2 to 1.21 km^2

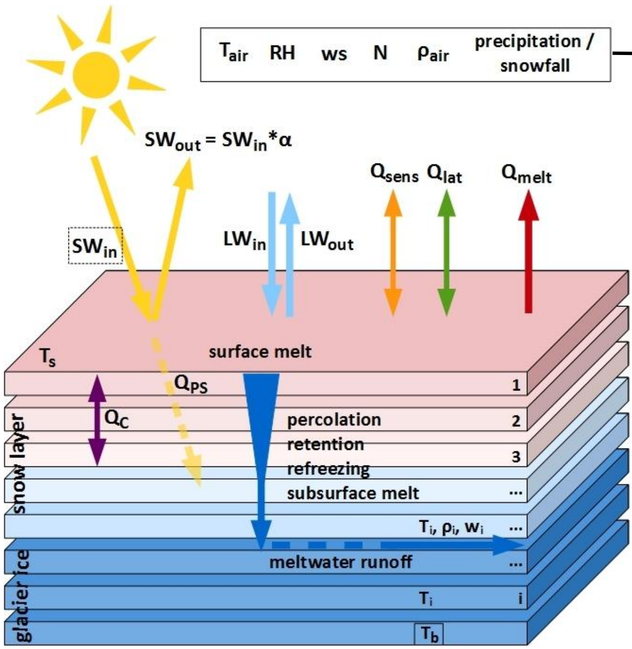
Over the time span from 1962 to 2023, there has been a consistent linear growth in the lake's extent, which has been amplified by the growth factor of ~6.

This expansion of 350% from 1962 to 2023 correlates significantly with mass loss from Gepang Gath glacier.

Pratap et al, 2024

Surface energy and mass balance model

COSIMA- COupled Snowpack and Ice surface energy and MAss balance model



Eva Huintjes & others (2015)

Initialization of COSIMA → Calculate the Surface Energy → Calculate the Surface Melt → Calculate the Subsurface Melt → Calculate the Mass Balance

❖ **The energy fluxes [Wm^-2]** at the glacier surface:

$$Q_{melt} = S_{net} + L_{net} + H_{se} + H_{la} + G$$

Where, Q_{metl} :: Melt energy

S_{net} :: Net shortwave radiation flux ($S_{net} = S_{in} - S_{out}$)

S_{net} :: net longwave radiation flux ($L_{net} = L_{in} - L_{out}$)

H_{se} :: Sensible flux

H_{la} :: Latent heat flux

G :: Ground heat flux

❖ **Surface Melt [m w.e.]**

$$M = \frac{Q_{melt}}{\rho_w L_f}$$

Where, ρ_w :: Density of water

L_f :: Latent heat of fusion (3.34 × 105 J kg^{-1})

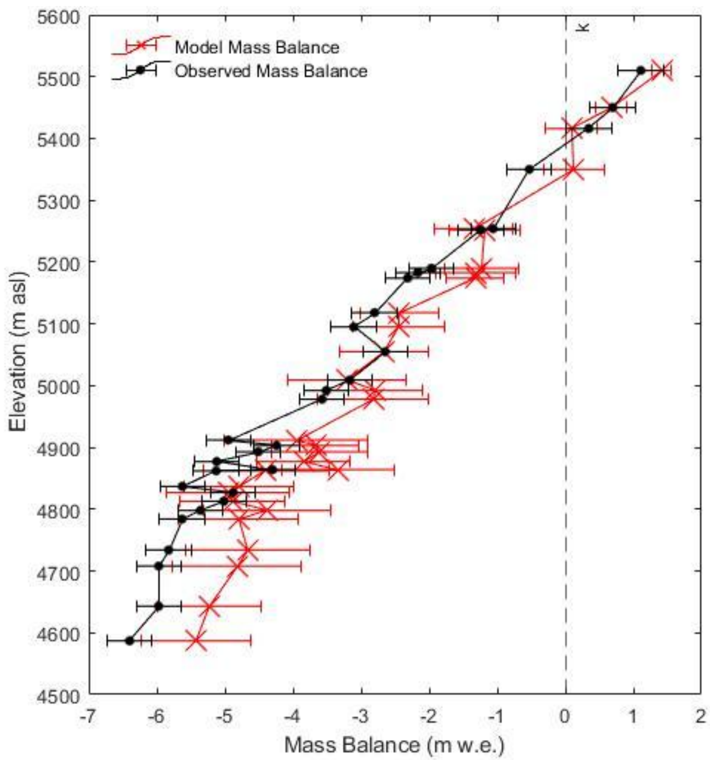
❖ **Subsurface Melt = Conduction heat flux + penetrating S_{net}**

❖ **Mass balance [m w.e.]**

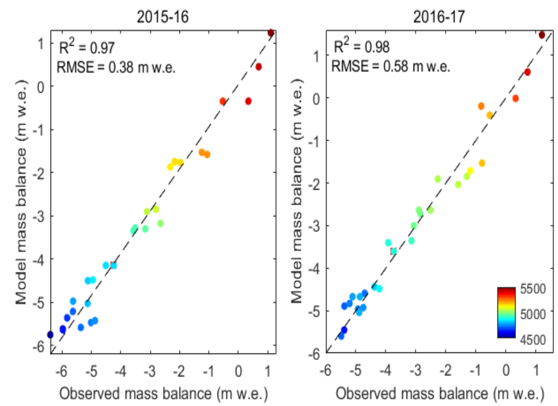
Mass Balance = Precipitation – Runoff – Evaporation

Where, Runoff = Rainfall + Subsurface Melt + Surface Melt – Refrozen water

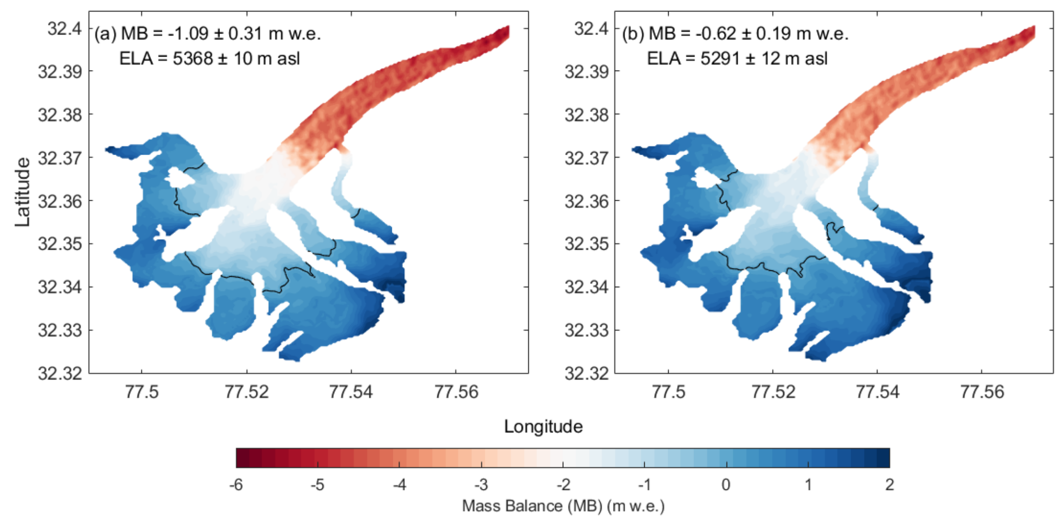
Comparison of observed and modelled mass balance (m w.e.) at Sutri Dhaka Glacier



Observed and modelled mass balance with uncertainty

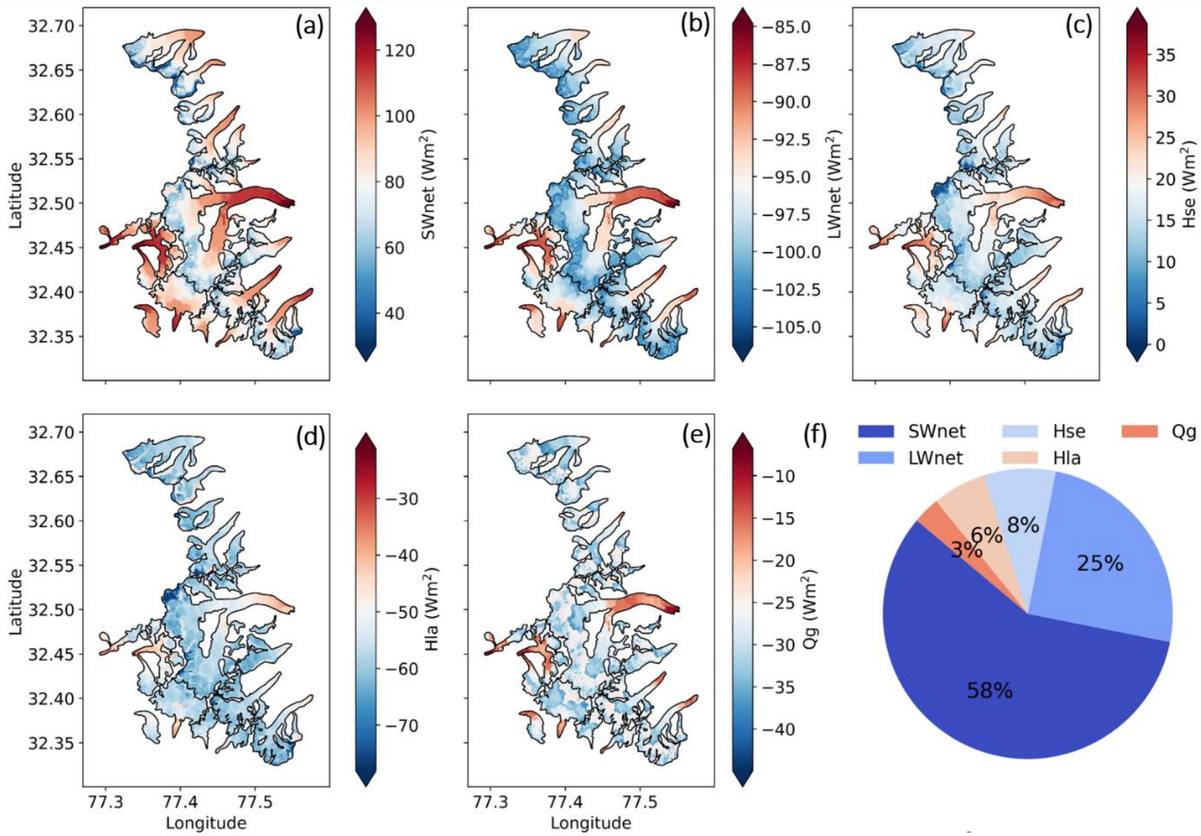


Comparison of observed and modelled mass balance



Distributed surface modelled annual mass balance at Sutri Dhaka Glacier

Distributed surface energy fluxes in the upper Chandra basin



Net shortwave: 30-130 Wm^2 (56%)

Net long wave: -106 to -84 Wm^2 (27%)

Sensible heat: 0-38 Wm^2 (8%)

Latent heat: -78 to -21 Wm^2 (5%)

Ground heat flux: -44 to -7 Wm^2 (4%)

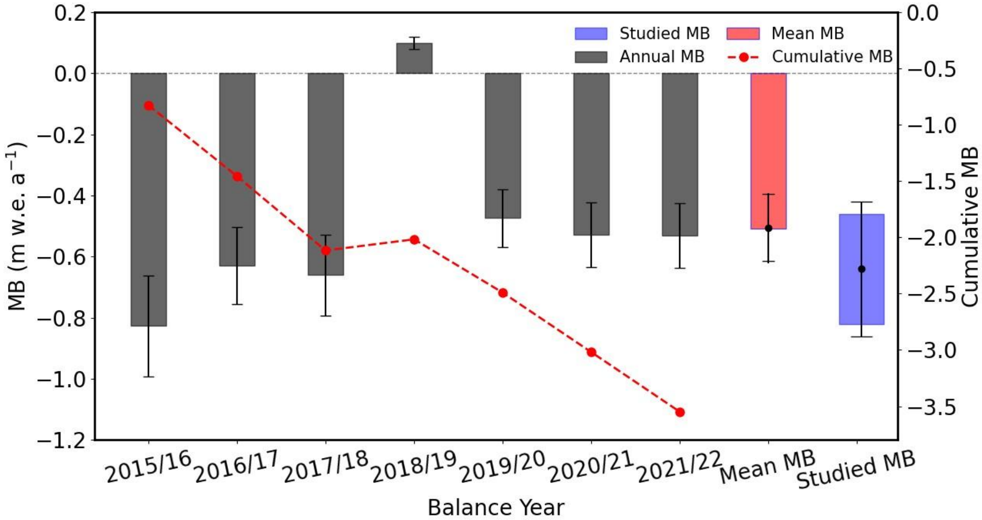
Installed AWS in the Chandra basin

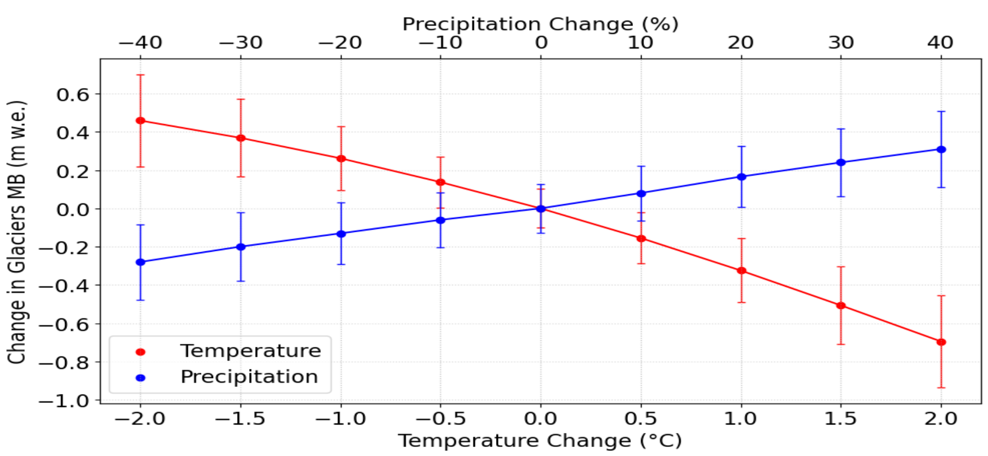
The shortwave radiation primarily determines the temporal variability of melting.

Long wave radiation is the largest energy sink that is substantially influenced by cloudy conditions.

Oulkar et al, 2024

Glacier Mass balance in Upper Chandra basin during 2013-2022



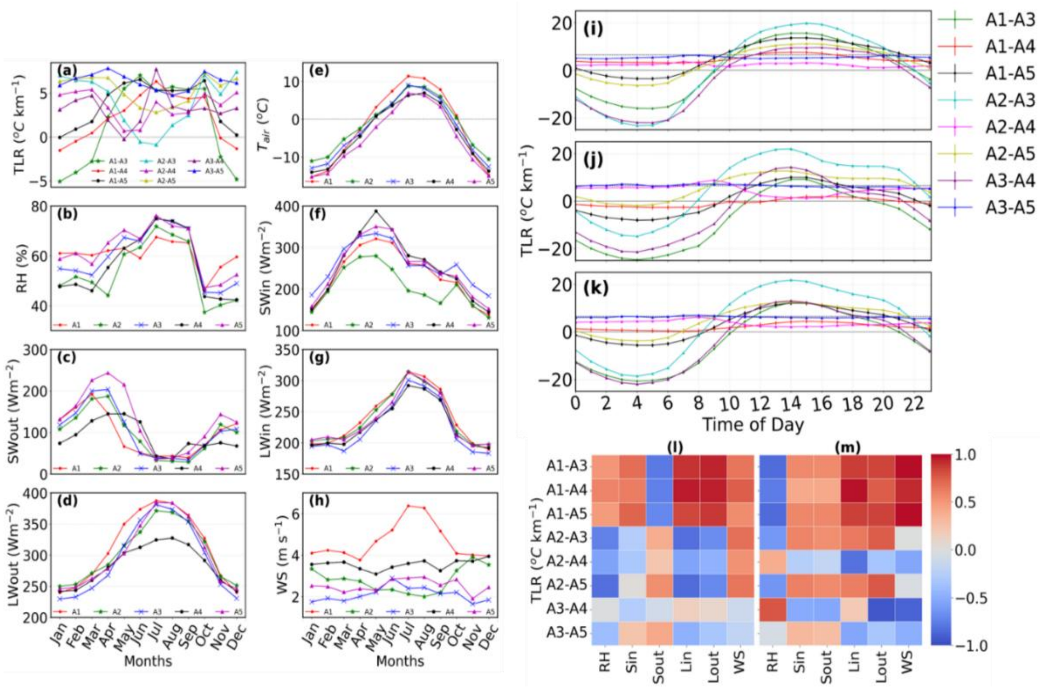


- The modelled annual MB ranges from -0.89 to 0.1 m w.e. with mean of -0.51 ± 0.28 m w.e. a^{-1}
- The modelled mean MB is consistent with the observed MB.

A temperature increase of 1 °C led to a 64% reduction in the total MB . In contrast, a temperature decrease of 1 °C resulted in a 51% increase in the MB.

Increasing the precipitation by 20% resulted in a 32% increase in the total MB, while a 20% decrease led to a 25% reduction in the total MB.

Temporal and spatial variability in air temperature lapse rates in Chandra basin

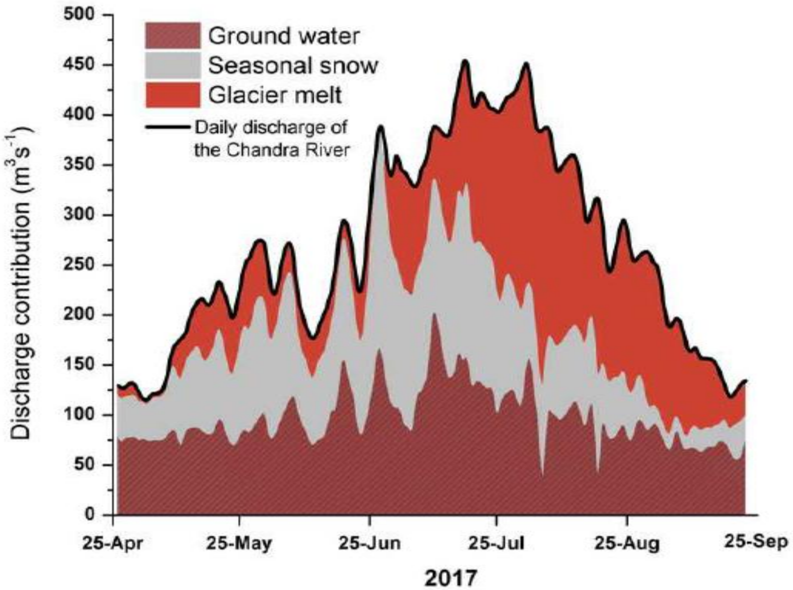


Over the Chandra Basin **(a)** mean monthly temperature lapse rate (TLR), **(b-h)** mean monthly meteorological variables. The diurnal variation during **(i)** summer, **(j)** winter, and **(k)** annual). Correlation matrix of **(l)** monthly and **(m)** diurnal TLR with corresponding meteorological variables over the study period.

- Mean annual TLR is 3.8 ± 0.3 °C km^{-1}
- Strong seasonal and diurnal variability in TLR
- Higher in the summer and lower in the winter.
- Maximum values during day time (10-18 hrs) and minimum during night (20 to 09 hrs).
- The modeled mean annual mass balance sensitivity is 0.3 m w.e. per °C km^{-1}.

Oulkar et al, 2024

Hydrological behaviors and hydrograph of Chandra river

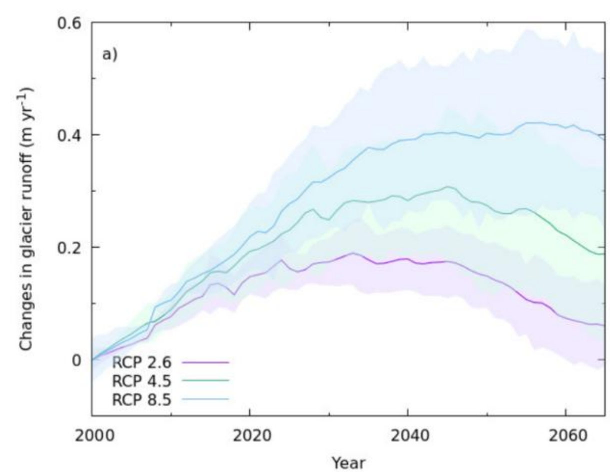


Hydrograph separation of the glacier melt, seasonal snow, and groundwater

- Source of River runoff :
- Groundwater (96.8 $m^3 s^{-1}$) : 38.3 ± 5.6%;
- Glacier melt (88.2 $m^3 s^{-1}$) : 30.9 ± 9%;
- Seasonal snowmelt (84.2 $m^3 s^{-1}$): 30.6 ± 5.7%;
- Infiltration of seasonal snowmelt (54%) and glacier melt (46%) mostly contribute to the groundwater recharge

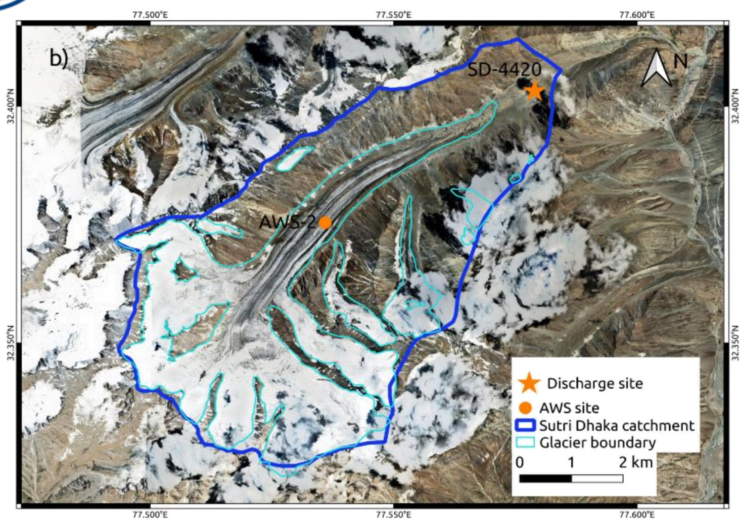
•1^{o}C rise in air temperature leading to 22 $m^3 s^{-1}$ (15% of mean) increase in the river discharge

Summer runoff from the glacierised parts are sensitive to temperature not precipitation changes however an opposite trends (sensitive to precipitation not for temperature) observed over non-glacierised parts.

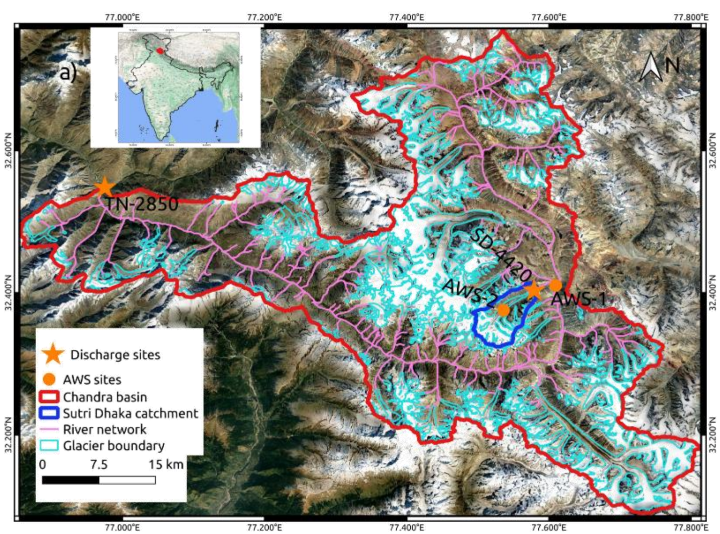


(Singh et al., 2020, 2021)

Variability in observed river discharge in Chandra basin



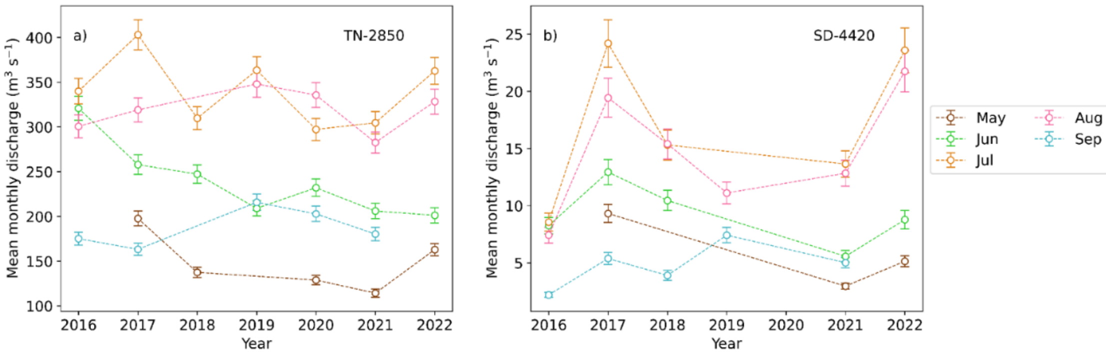
Sutri Dhaka catchment



Chandra basin catchment

	Sutri Dhaka catchment	Chandra basin
Area (km^2)	46	2446
Hydrological site name (site code)	Sutri Dhaka (SD-4420)	Tandi (TN-2850)
Hydrological site location (Lat, Lon)	32.403° N, 77.579° E	32.548° N, 76.975° E
Hydrological site elevation (m a.s.l)	4420	2850
Glacierised area (km^2)	22	631
Glacierised fraction	0.49	0.26
Debris cover area(km^2) /fraction(%)	1.5 (7%)	207 (28%)
Total no of glaciers (area > 0.2 km^2)	4	211
Elevation range (m a.s.l)	4389—6227	2800–6592
Mean elevation (m a.s.l)	5278	4841
Mean slope (°)	29	28

Trends in monthly discharge during 2013-2022



Monthly discharge time series for the discharge sites (a) Tandi (Chandra basin) and (b) Sutri Dhaka, respectively.

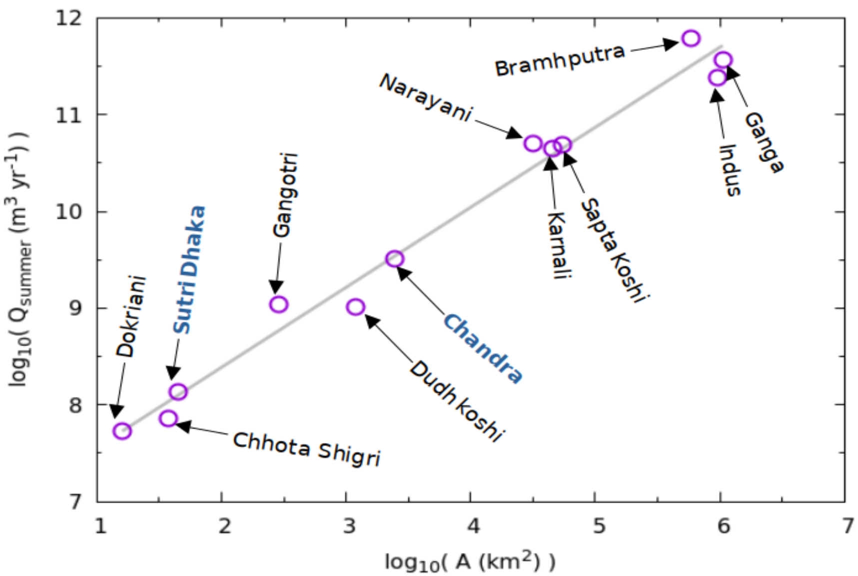
In the Chandra basin, inter-annual variability in monthly discharge varied between 7–21% of mean monthly discharge during May–September, with maximum and minimum in May and August respectively.

Sutri Dhaka catchment: Monthly discharge varied between 26–45% of mean monthly discharge during May–September, with maximum and minimum in May and June respectively.

Maximum interannual variability of monthly discharge was found at the Sutri Dhaka catchment due to highly glacierised catchment

The seasonal pattern of the discharge variations follows the corresponding temperature variations

Relationship between total catchment/basin area and summer discharge



Volumetric summer discharge (Q_{summer}) variations with catchment areas (A) between different catchments/basins with observed discharge over the Himalayan arc. The solid gray line is the best-fit line

The summer discharge values from different locations over the Himalayan arc and their corresponding catchment area follow a linear dependence on a log-scale plot

$\log_{10} Q_{summer} = (0.83 \pm 0.04) \log_{10} A + (6.68 \pm 0.15).$

A small glacier catchment or large basin area over the Himalaya, we can approximately predict the mean summer discharge using above equation

Key Points

1. All the studied glaciers have experienced strong negative balance during last 10 years except 2018-19 in Chandra basin.
2. Lake terminating glaciers loose relatively higher glacier mass.
3. Debris covered glacier experienced lower mass wastage.
4. COSIMA model works well to estimate surface energy and mass balance over clean glacier.
5. The shortwave radiation primarily determines the temporal variability of melting. However, longwave radiation is the largest energy sink.
6. Surface mass balance is more sensitive to temperature than precipitation.
7. Strong seasonal and diurnal variability observed in TLR.
8. Summer runoff from the glacierised parts are sensitive to temperature not precipitation changes
9. A strong diurnal variability in discharge due to temperature-induced snow and glacier ice melt.
10. The temperature sensitivity is maximum during peak discharge month
11. The simple linear response model can also predict the observed discharge variability with reasonable accuracy.


THANK YOU