Understanding the Gangotri glacier dynamics: Implications from a fully distributed inversion of equivalent water-volume change

Supplementary dataset

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Table S1: Dataset used for COSI Corr and ImGRAFT toolbox

Pairs	Data	Master image	Slave image	Time baseline (days)
1	Sentinel-2	2016.09.19	2017.08.15	331
2	Sentinel-2	2017.08.15	2018.08.09	359
3	Sentinel-2	2018.08.09	2019.09.14	400
4	Sentinel-2	2019.09.14	2020.10.08	342
5	Sentinel-2	2020.10.08	2021.10.13	370
6	Sentinel-2	2021.10.13	2022.10.28	351
7	Sentinel-2	2022.10.28	2023.10.28	365

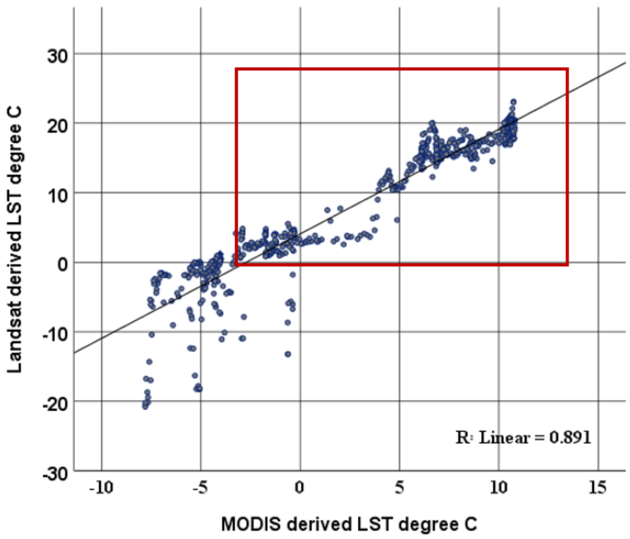

Figure S1: Correlation between MODIS derived and Landsat derived LST of Gangotri glacier for assessment the accuracy of the MODIS coarse dataset

Table S2: Correlation between MODIS (2022) derived and Landsat (2022) derived LST of Gangotri

		Landsat derived LST	MODIS LST
Landsat derived LST	**Pearson Correlation**	**1**	**.944****
	Sig. (2-tailed)		**.000**
	N	**682**	**682**
MODIS LST daytime	**Pearson Correlation**	**.944****	**1**
	Sig. (2-tailed)	**.000**	
	N	**682**	**682**

Supplementary text

1. Arehenius creep factor estimation:

$$A_c = A_c^* \exp\left(\frac{Q_c}{R}\left[\frac{1}{T} - \frac{1}{T^*}\right]\right)$$

where the constants being $A_c^* = 2.4 \cdot 10^{-24}, Q_c = 115$ kJ $\text{mol}^{-1}, R \approx 0.0083145$ (the ideal gas constant), and $T^* = 273$ K , T is estimated land surface temperature (LST).

Table S3: Estimated Arehenius creep factor

Year	Min LST (°C)	Max. LST (°C)	Min LST (Kelvin)	Max LST (Kelvin)	Arehenius creep factor
2016	-18.54	11.27	254.61	284.42	1.553e-23
2017	-18.46	10.48	254.69	283.63	1.576e-23
2018	-20.02	9.77	253.13	282.92	2.112e-23
2019	-19.82	8.13	253.33	281.28	2.162e-23
2020	-19.52	9.97	253.63	283.12	1.920e-23
2021	-18.90	9.56	254.25	282.71	1.760e-23
2022	-17.61	13.05	255.54	286.2	1.256e-23
2023	-17.62	12.06	255.53	285.21	1.296e-23
Mean	-18.81	10.50	254.82	283.65	1.526e-23

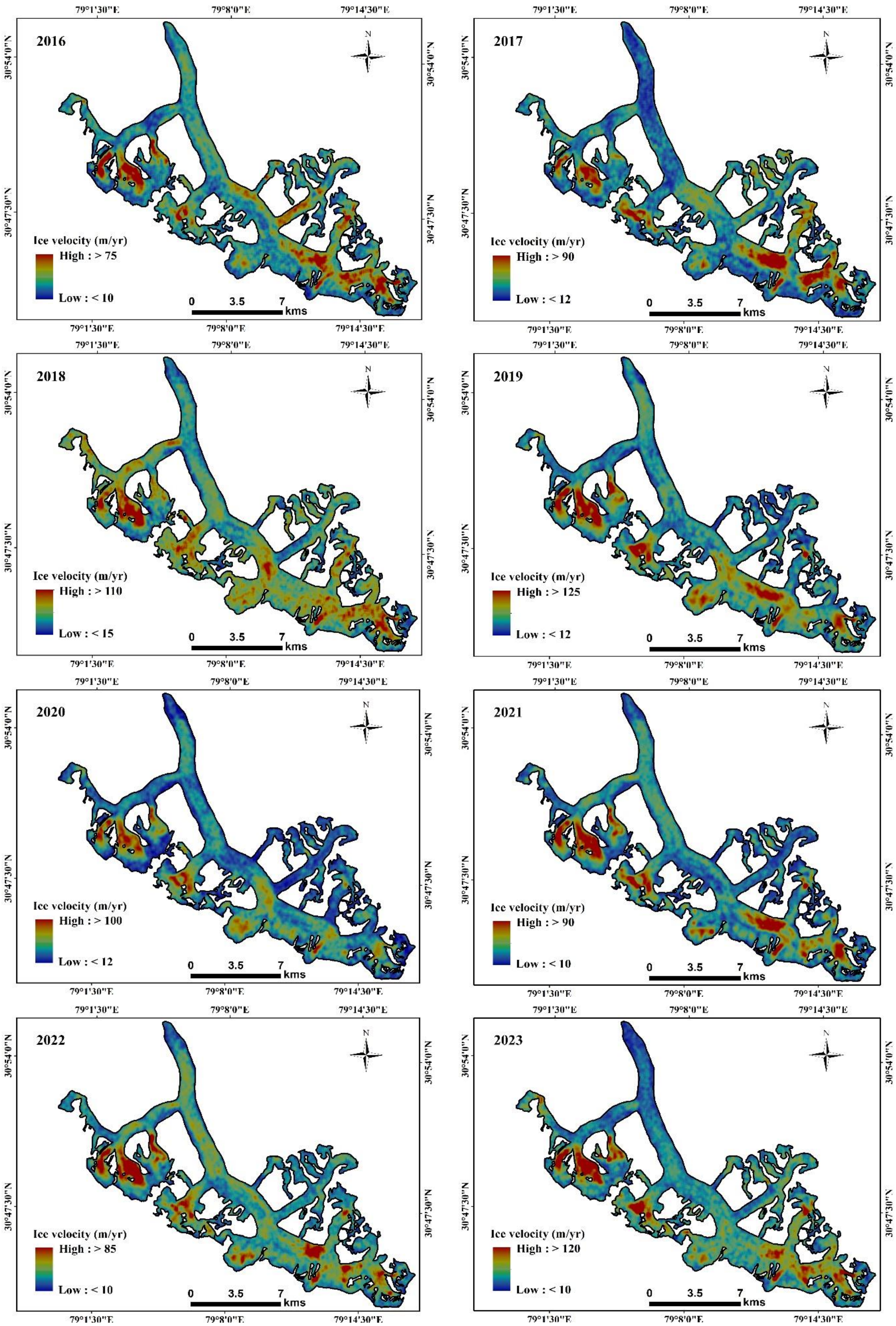

Figure S2: GIV derived velocity map 2016 to 2023

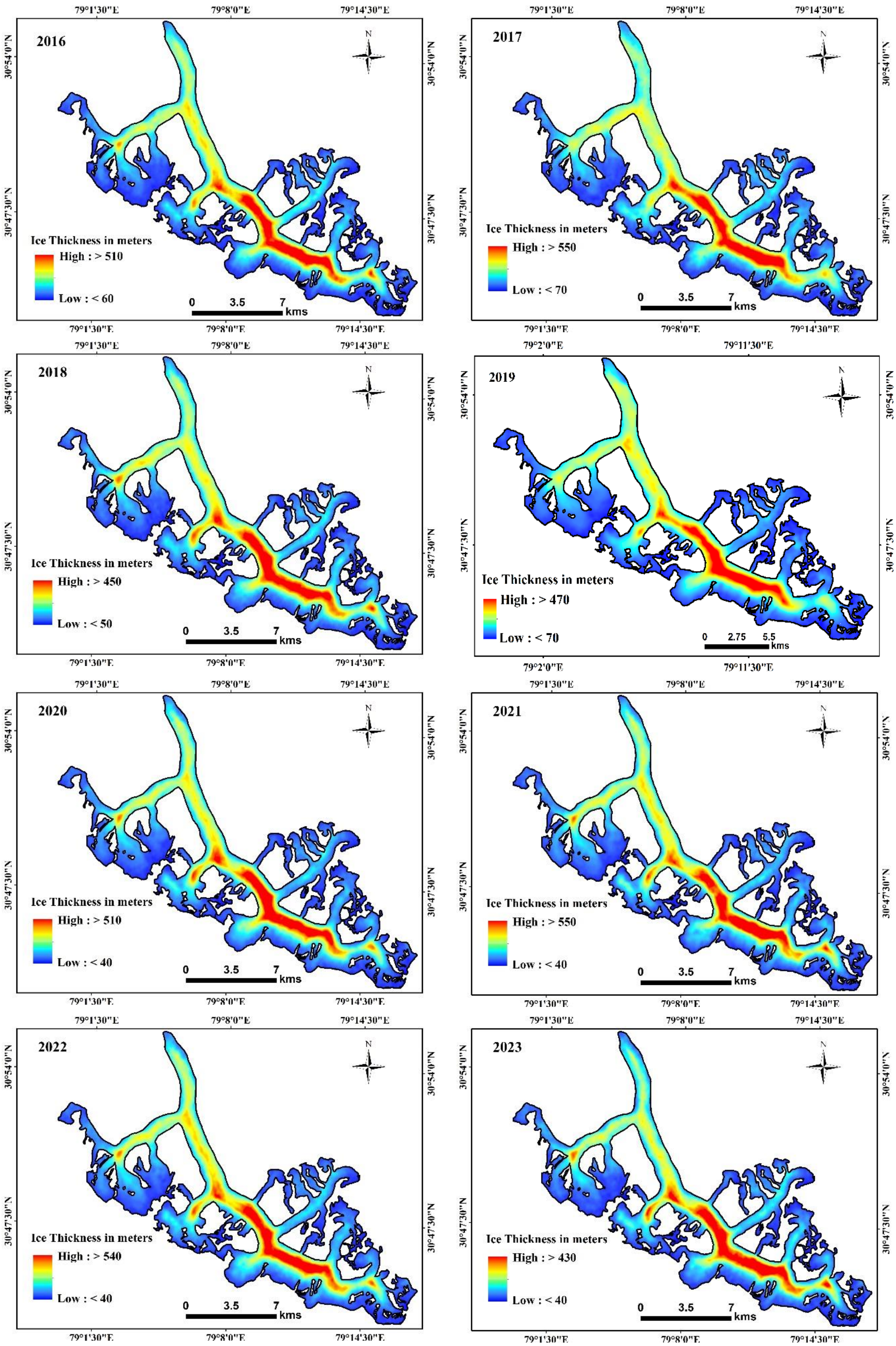

Figure S3: 2016 to 2023 thickness based on VWDV model

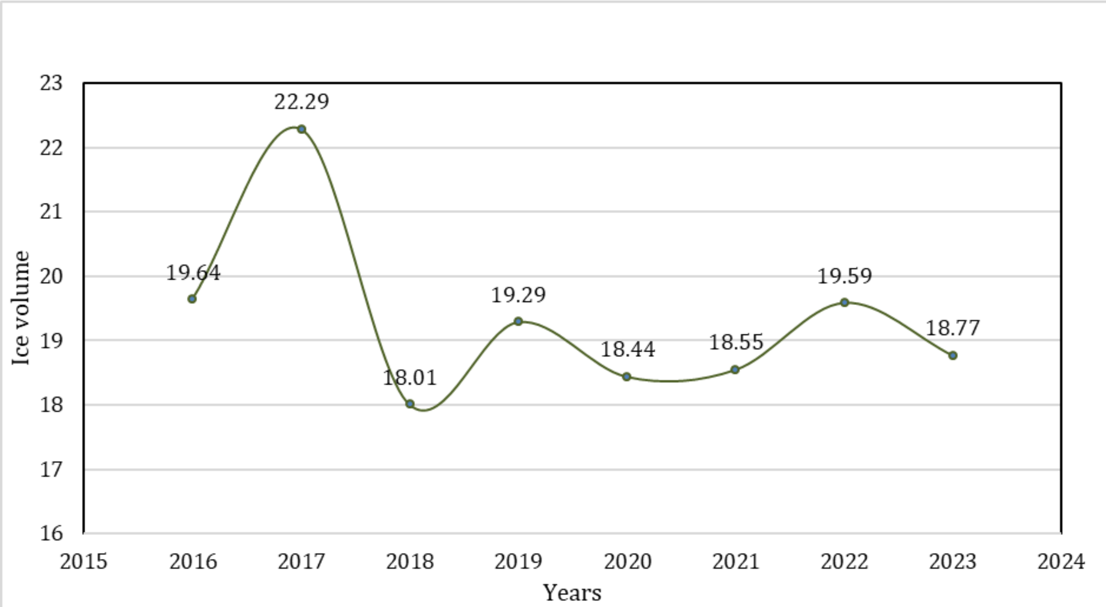

Figure S4: Ice volume (km^3) estimated by modified area of the glacier (area*thickness)

2. Comparative assessment of the Glaciological mass balance Garhwal Himalaya glaciers:

In Garhwal Himalaya, four glaciers; Dunagiri, Tipra Bank, Chorabari, and Dokriani were surveyed for their annual mass balances (Azam et al., 2018).
It includes annual mass balance estimates covering different observation periods for each glacier, along with their correlations with temperature and precipitation anomalies. Tipra Bank Glacier exhibited near-equilibrium conditions with a mean annual mass balance of –0.14 m w.e. a^{-1} from 1981 to 1988, whereas Dunagiri Glacier experienced significant mass loss, averaging –1.04 m w.e. a^{-1} between 1984 and 1990. Dokriani Glacier recorded mass balance values of –0.25 m w.e. a^{-1} from 1992 to 1995 and –0.39 m w.e. a^{-1} from 1997 to 2000, while Chorabari Glacier exhibited an annual mass balance of –0.73 m w.e. a^{-1} during 2003–2010.

Comparing these values with Gangotri Glacier, which has a mean annual mass balance of –-1.01 ± 0.403 m w.e. a^{-1} , highlights the impact of extensive debris cover (Yousuf et al., 2025), particularly in the ablation zone. The presence of thick debris cover significantly influences melt rates, leading to heterogeneous mass loss patterns. While Tipra Bank and Dunagiri glaciers exhibited a strong correlation ($r^2 = 0.75$) over 1985–1988, indicating similar climatic responses, the high mass wastage observed in Gangotri Glacier suggests additional controlling factors beyond climate alone.

Table S4: Glaciological Mass Balance Measurements in the Garhwal Himalaya (Azam et al., 2018).

Glacier name	Location	Area (km^2)	Aspect	MB Period	Mass balance (m w.e. yr^{-1})	Reference
1. Chorabari (CB)	30°74’N 79°09’E	6.7	S	2003-2010	–0.73	Dobhal et al., (2013)
2. Dokriani (DR)	30°50’N 78°50’E	7.0	NW	1992-1995; 1997-2000;	–0.32	Dobhal et al., (2013)
3. Dunagiri (DG)	30°33’N 79°54’E	2.6	N	1984-1990	–1.04	GSI (1991)

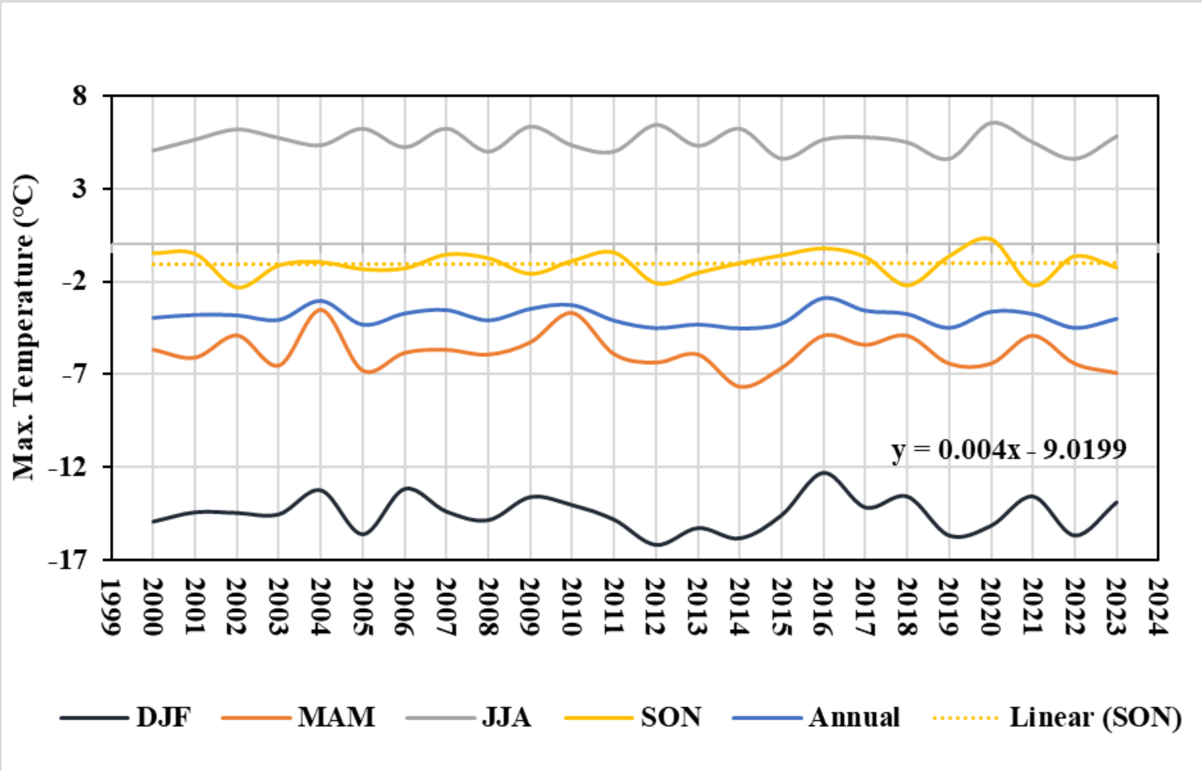

Figure S5: Graph showing the trend of seasonal maximum temperature of the Gangotri glacier

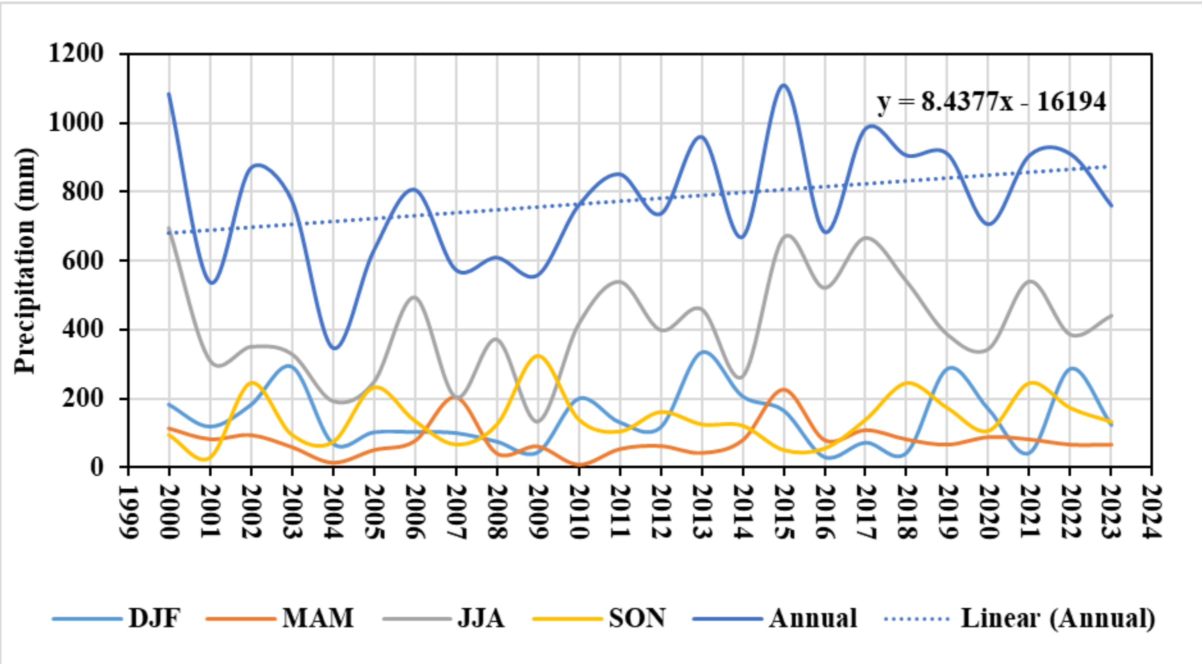

Figure S6: Graph showing the trend of seasonal and annual precipitation of the Gangotri glacier

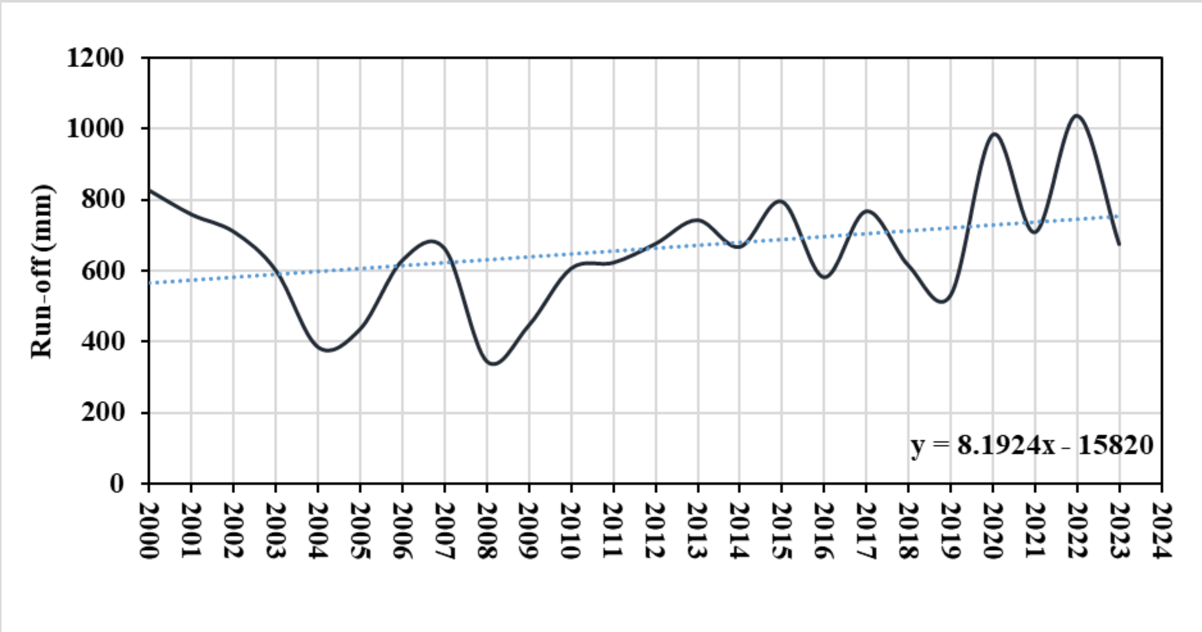

Figure S7: Graph showing the total runoff trend of the Gangotri glacier of the month of May-June-July-August-September

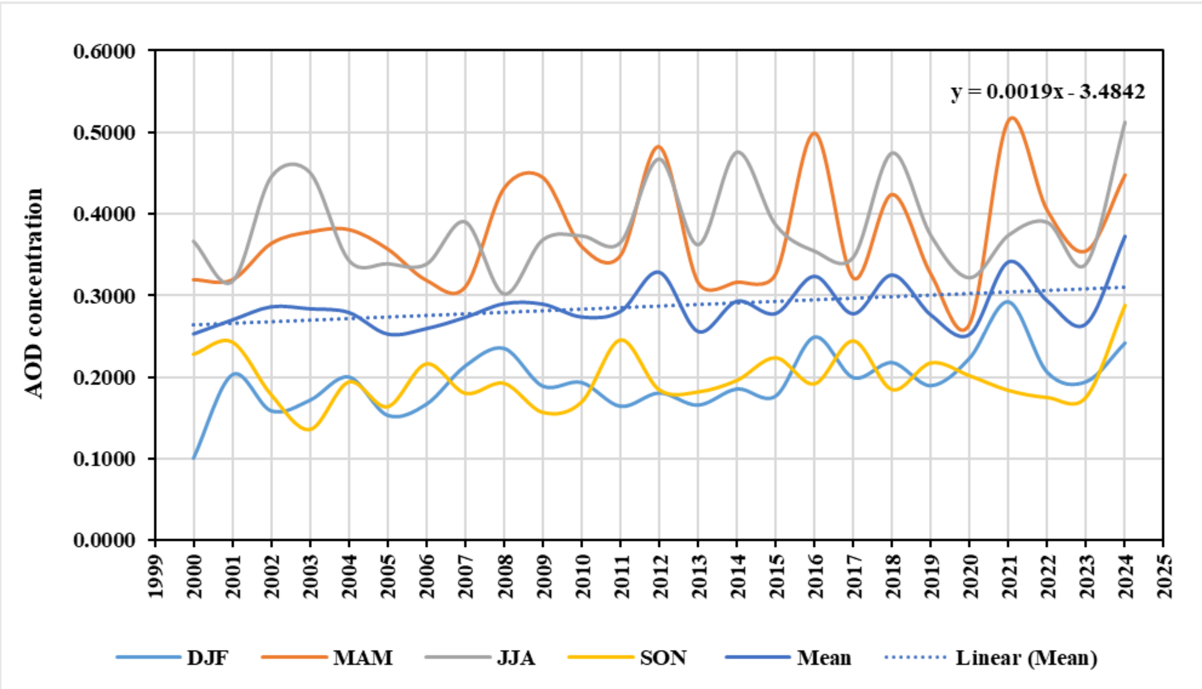

Figure S8: Graph showing the seasonal Aerosol Optical Depth (AOD) concentration in Uttarakhand state

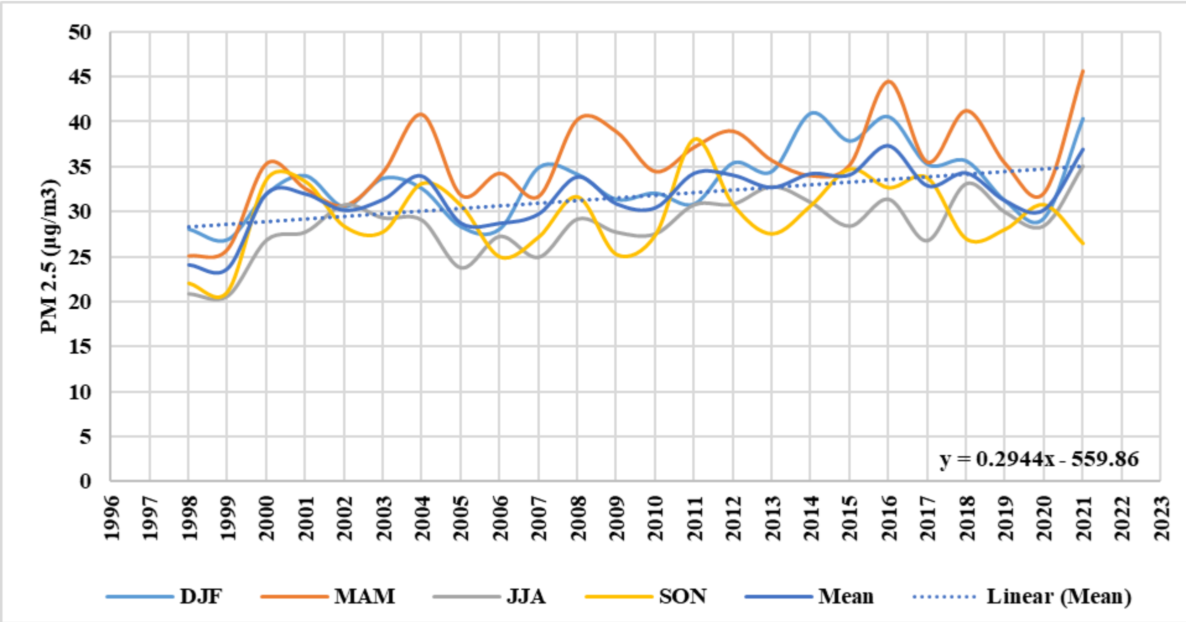

Figure S9: Graph showing the seasonal PM 2.5 concentrations in Uttarakhand state

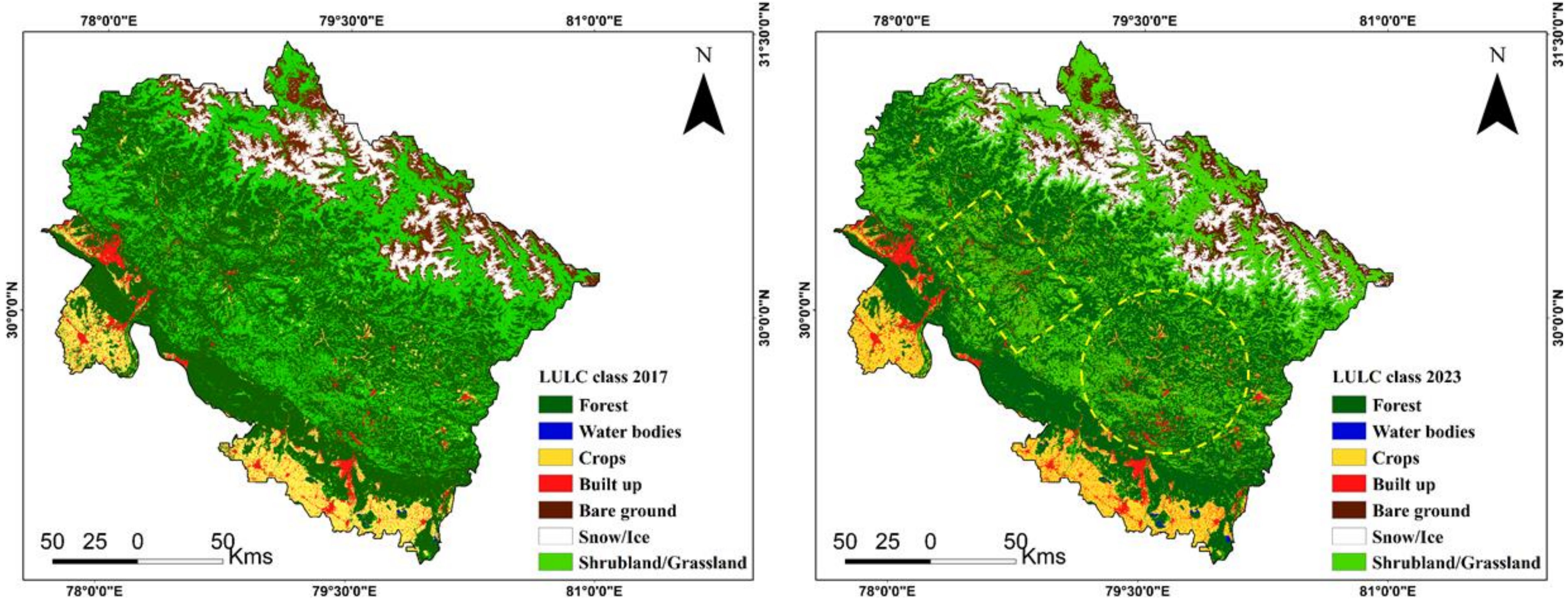

Figure S10: Land Use Land Cover (LULC) changes in Uttarakhand state from 2017 to 2023, derived from Sentinel-2 data. The results indicate a significant increase in built-up areas, while deforestation is also observed.

References

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