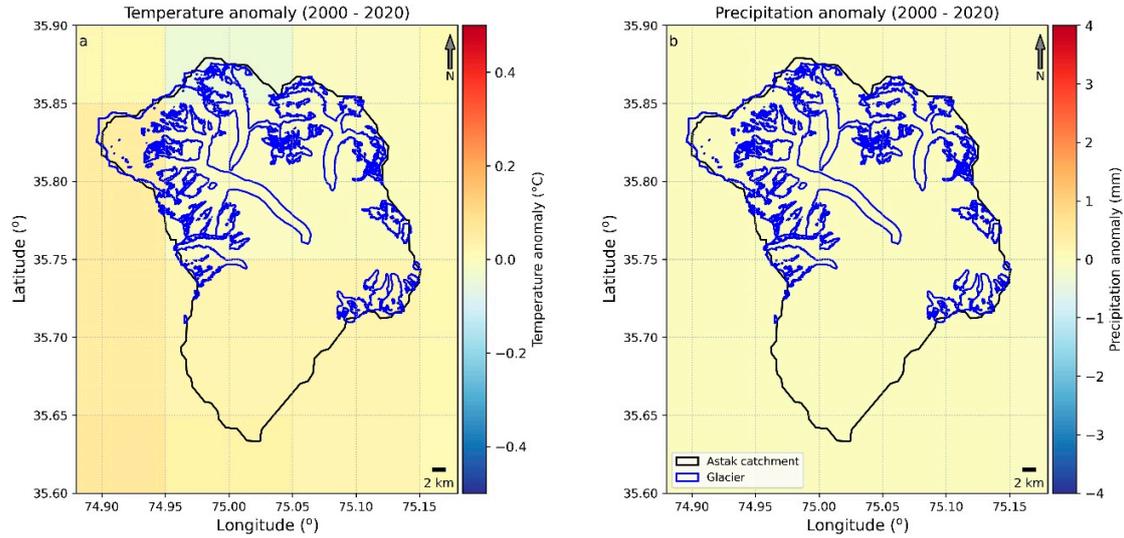


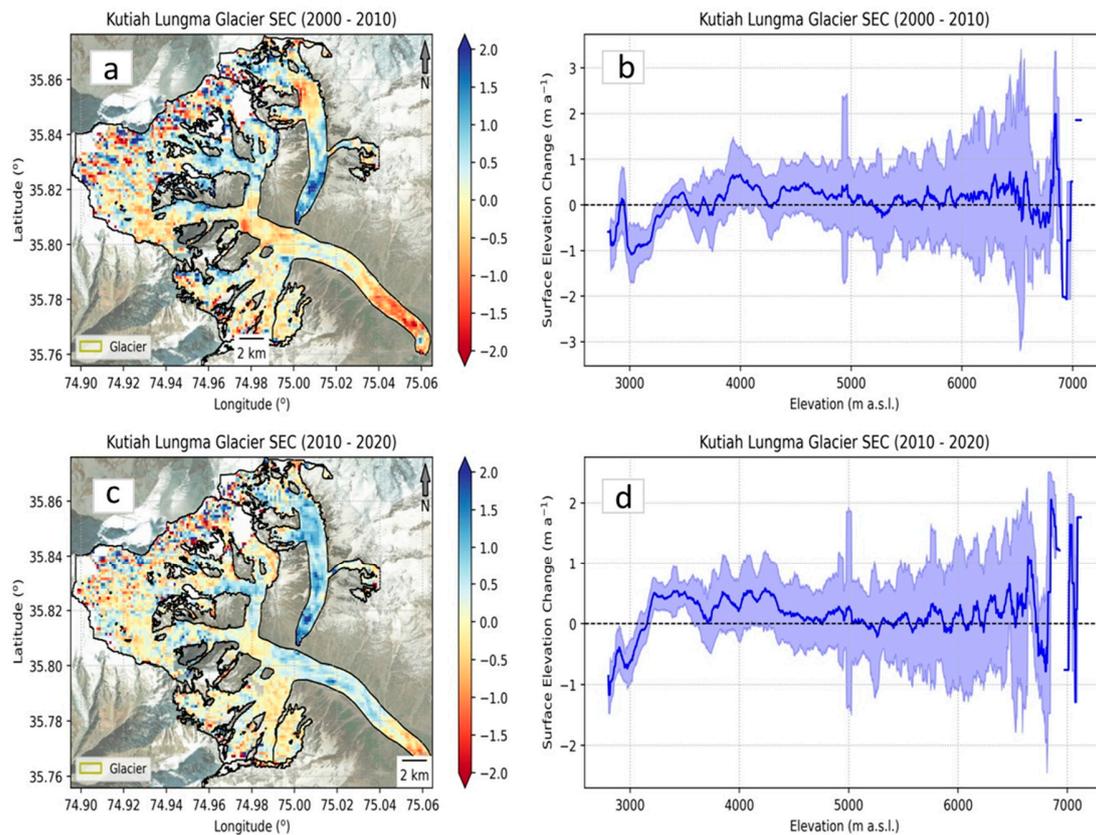
*Supplementary materials*

**Two-decadal Glacier Changes in the Astak, a Tributary Catchment of the Upper Indus River in Northern Pakistan**

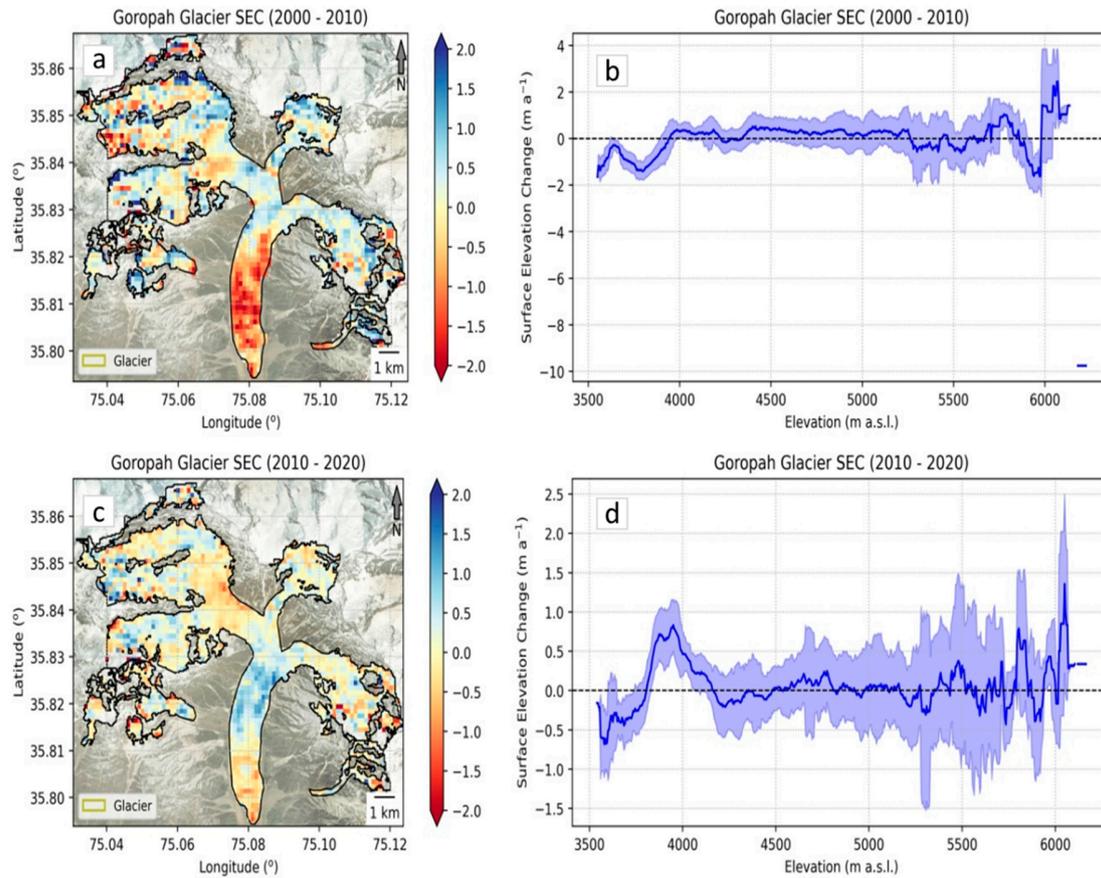
**Supplementary Figures**



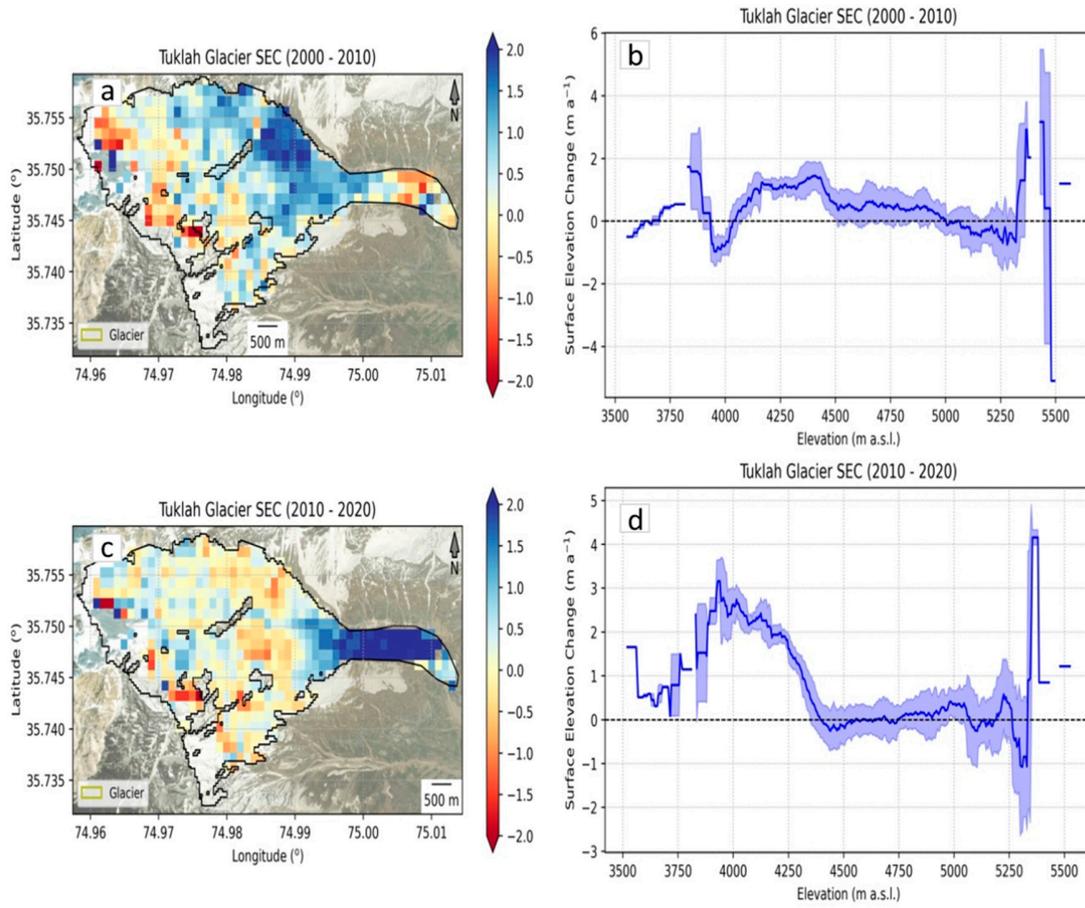
**Figure S1.** Mean annual climate change anomalies for the Astak catchment from 2000 to 2020 compared to the baseline period 1990 to 2000. (a) Temperature anomalies, and (b) precipitation anomalies. Boundary of Astak catchment is shown in black and glacier boundaries are shown in blue.



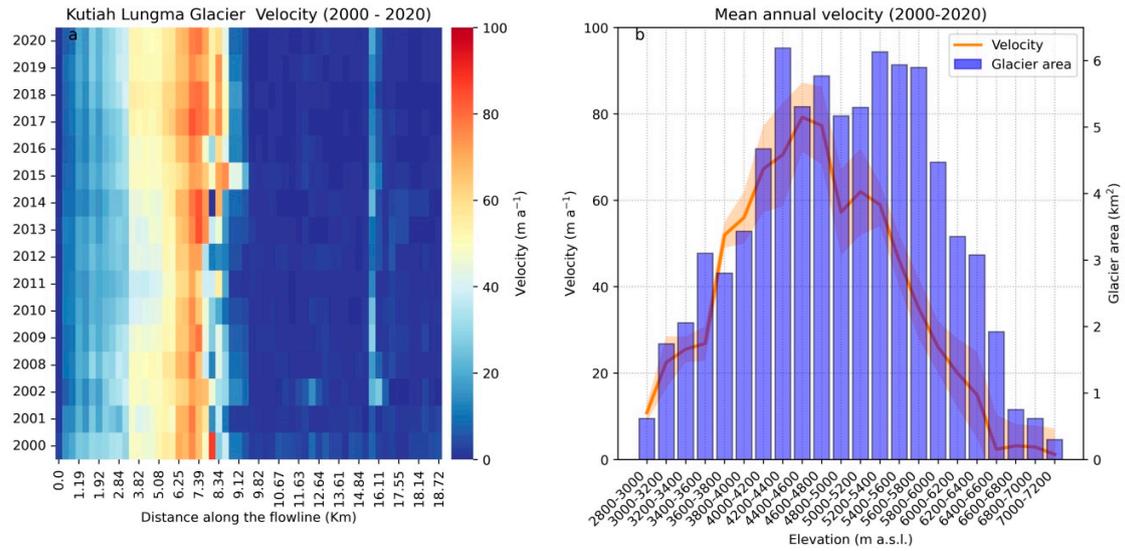
**Figure S2.** (a) Spatially distributed elevation change for Kutiah Glaceir and it tributaries from 2000 to 2010. The changes in color corresponds to the change in glacier surface elevation shown in the color bar. (b) Altitudinal variations in glacier elevation change shown with the blue line at each 50 meter in-terval. Range of error at each point is shown in the blue shaded line. And the glacier elevation changes for the period of 2010 to 2020 is shown in panel c and d.



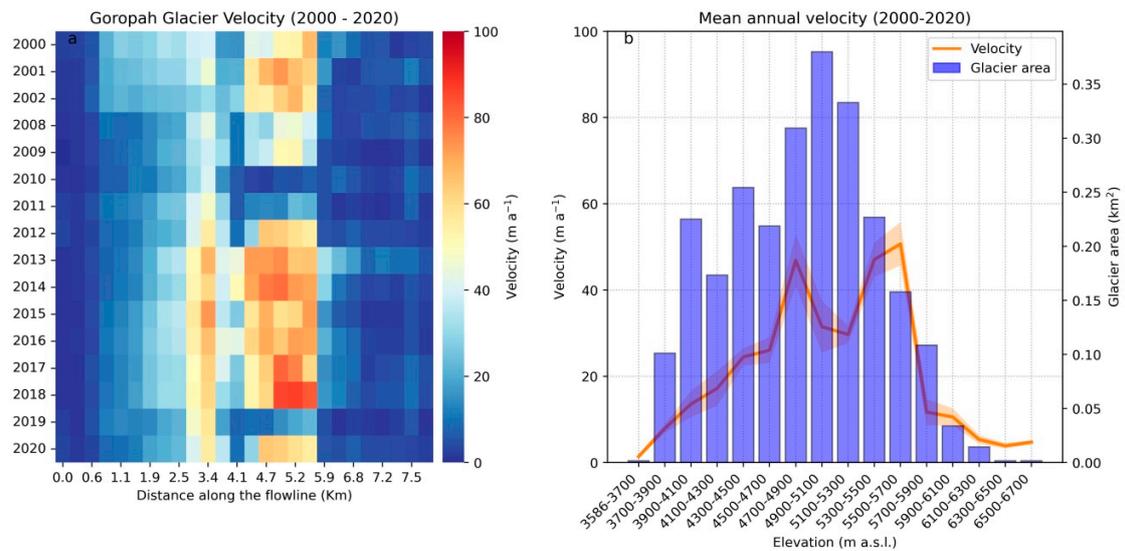
**Figure S3.** (a) Spatially distributed elevation change for Goropah Glaceir and it tributaries from 2000 to 2010. The changes in color corresponds to the change in glacier surface elevation shown in the color bar. (b) Altitudinal variations in glacier elevation change shown with the blue line at each 50 meter in-terval. Range of error at each point is shown in the blue shaded line. And the glacier elevation changes for the period of 2010 to 2020 is shown in panel c and d.



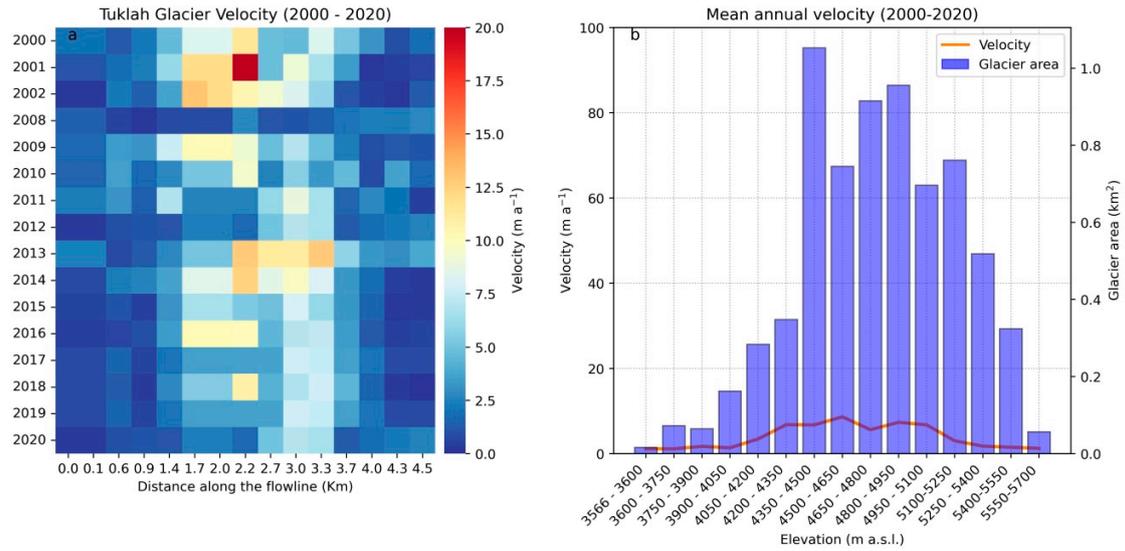
**Figure S4.** (a) Spatially distributed elevation changes for Tuklah Glaceir and it tributaries from 2000 to 2010. The changes in color corresponds to the change in glacier surface elevation shown in the color bar. (b) Altitudinal variations in glacier elevation change shown with the blue line at each 50 meter in-terval. Range of error at each point is shown in the blue shaded line. And the glacier elevation changes for the period of 2010 to 2020 is shown in panel c and d.



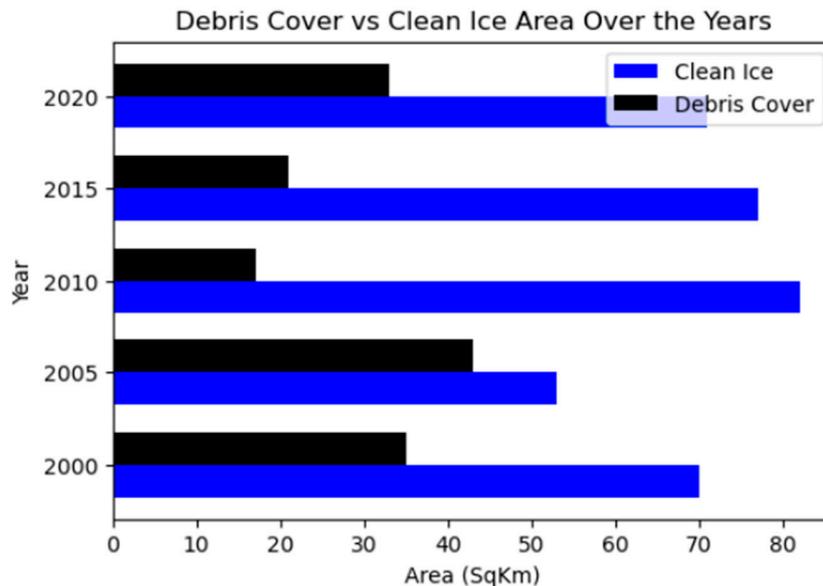
**Figure S5.** (a) Variation in Kutiah Lungma Glacier velocity from 2000 to 2020. Distance away from the glacier terminus is presented along x-axis and the mean annual velocity is shown in y-axis. (b) Altitudinal variation in glacier velocity is shown with the brown line corresponds to the primary y-axis and the glacier area at each 200 m elevation bin is shown with the blue bar corresponds to the secondary y-axis.



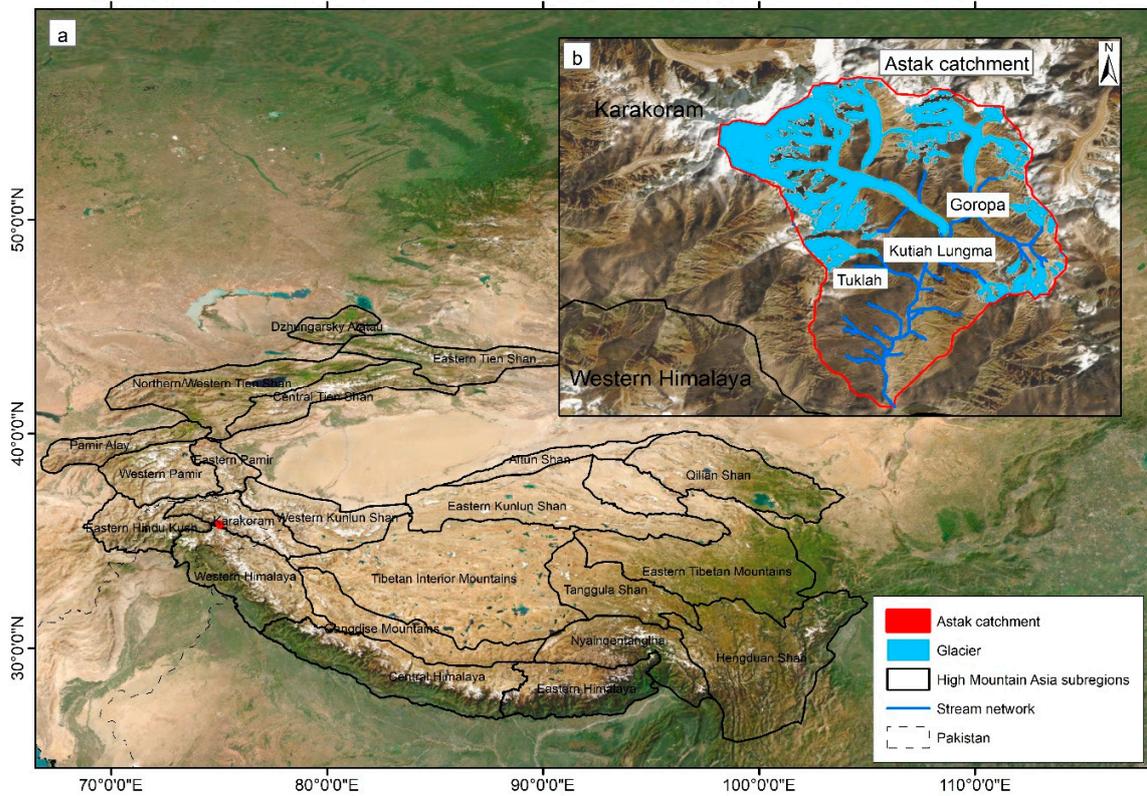
**Figure S6.** (a) Variation in Goropah Glacier velocity from 2000 to 2020. Distance away from the glacier terminus is presented along x-axis and the mean annual velocity is shown in y-axis. (b) Altitudinal variation in glacier velocity is shown with the brown line corresponds to the primary y-axis and the glacier area at each 200 m elevation bin is shown with the blue bar corresponds to the secondary y-axis.



**Figure S7.** (a) Variation in Tuklah Glacier velocity from 2000 to 2020. Distance away from the glacier terminus is presented along x-axis and the mean annual velocity is shown in y-axis. (b) Altitudinal variation in glacier velocity is shown with the brown line corresponds to the primary y-axis and the glacier area at each 200 m elevation bin is shown with the blue bar corresponds to the secondary y-axis.



**Figure S7.** Temporal variations in debris covered and clean-ice glacier in the Astak catchment. Debris cover glacier area for the corresponding year is shown in black bar and blue bar represents the clean-ice glacier area.



**Figure S8.** (a) The geographical extent of High Mountain Asia (HMA) with all subregions highlighted by black boundaries. The location of the Astak catchment within HMA is indicated by the red polygon. (b) The boundary of the Astak catchment is outlined in red, with glaciers highlighted by gray boundaries.

## Supplementary tables

**Table S1.** Details of the optical satellite images from Landsat images used for the estimation of glacier area change in Astak catchment.

Acquisition Date	Product ID	Path/Row	Resolution(m)	Cloud Cover %
11/9/2000	LE07_L1TP_149035_20000911_20200918_02_T1	149/35	30	2.61
24/8/2005	LE07_L1TP_149035_20050824_20200914_02_T1	149/35	30	5.35
22/08/2010	LE07_L1TP_149035_20100822_20200911_02_T1	149/35	30	3.18
20/8/2015	LE07_L1TP_149035_20150820_20200903_02_T1	149/35	30	2.94
17/08/2020	LE07_L1TP_149035_20200817_20200917_02_T1	149/35	30	3.45

**Table S2.** Details of the ASTER DEMs used for the estimation of glacier surface elevation change from 2000 to 2020 for the Astak catchment.

Acquisition Date	Sensor	Resolution	Cloud Cover %
9/7/2000	ASTER V003	30	11
30/9/2001	ASTER V003	30	5
22/8/2002	ASTER V003	30	34
29/10/2003	ASTER V003	30	11
13/09/2004	ASTER V003	30	01
15/10/2004	ASTER V003	30	13
5/11/2005	ASTER V003	30	26
28/11/2005	ASTER V003	30	46
12/09/2006	ASTER V003	30	16
1/5/2007	ASTER V003	30	37
27/11/2008	ASTER V003	30	20
03/10/2008	ASTER V003	30	03
14/11/2009	ASTER V003	30	20
14/11/2009	ASTER V003	30	29
17/11/2010	ASTER V003	30	16
17/11/2010	ASTER V003	30	28
12/10/2011	ASTER V003	30	06
30/10/2012	ASTER V003	30	12
6/09/2013	ASTER V003	30	03
6/09/2013	ASTER V003	30	06
18/09/2014	ASTER V003	30	04
27/8/2015	ASTER V003	30	19
27/8/2015	ASTER V003	30	34
23/9/2016	ASTER V003	30	04
12/10/2017	ASTER V003	30	21

5/8/2018	ASTER V003	30	04
10/11/2019	ASTER V003	30	21
10/11/2019	ASTER V003	30	19
17/08/2020	ASTER V003	30	01

**Table S3.** Details of satellite images used for the extraction of glacier surface velocity in the Astak catchment from 2000 to 2020.

Acquisition Date	Product ID	Path/Row	Resolution(m)	Cloud Cover %
29/10/2000	LE07_L1TP_149035_20001029_20200918_02_T1	149/35	30	02
30/09/2001	LE07_L1TP_149035_20010930_20200917_02_T1	149/35	30	1.0
3/10/2002	LE07_L1TP_149035_20021003_20200916_02_T1	149/35	30	2.0
31/7/2008	LE07_L1TP_149035_20080731_20200912_02_T1	149/35	30	1.0
20/09/2009	LE07_L1TP_149035_20090920_20200911_02_T1	149/35	30	1.0
22/08/2010	LE07_L1TP_149035_20100822_20200911_02_T1	149/35	30	4.0
12/10/2011	LE07_L1TP_149035_20111012_20200909_02_T1	149/35	30	2.0
30/10/2012	LE07_L1TP_149035_20121030_20200908_02_T1	149/35	30	2.0
7/9/2013	LC08_L1TP_149035_20130907_20200912_02_T1	149/35	30	2.14
26/09/2014	LC08_L1TP_149035_20140926_20200910_02_T1	149/35	30	5.19
31/10/2015	LC08_L1TP_149035_20151031_20200908_02_T1	149/35	30	3.94
14/08/2016	LC08_L1TP_149035_20160814_20200906_02_T1	149/35	30	45.52
1/8/2017	LC08_L1TP_149035_20170801_20200903_02_T1	149/35	30	3.60
4/8/2018	LC08_L1TP_149035_20180804_20200831_02_T1	149/35	30	2.57
24/09/2019	LC08_L1TP_149035_20190924_20200826_02_T1	149/35	30	1.11
15/07/2020	LC08_L1TP_149035_20200825_20200905_02_T1	149/35	30	5.50