Current glacier status and ELA changes since the Late Pleistocene in the Hindu Kush Mountains of Afghanistan

Presenter: Mohammad Tayib Bromand

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Esmatullah Joya [a], Mohammad Tayib Bromand [b], Khalid Omar Murtaza [c], Reyaz Ahmad Dar [c]

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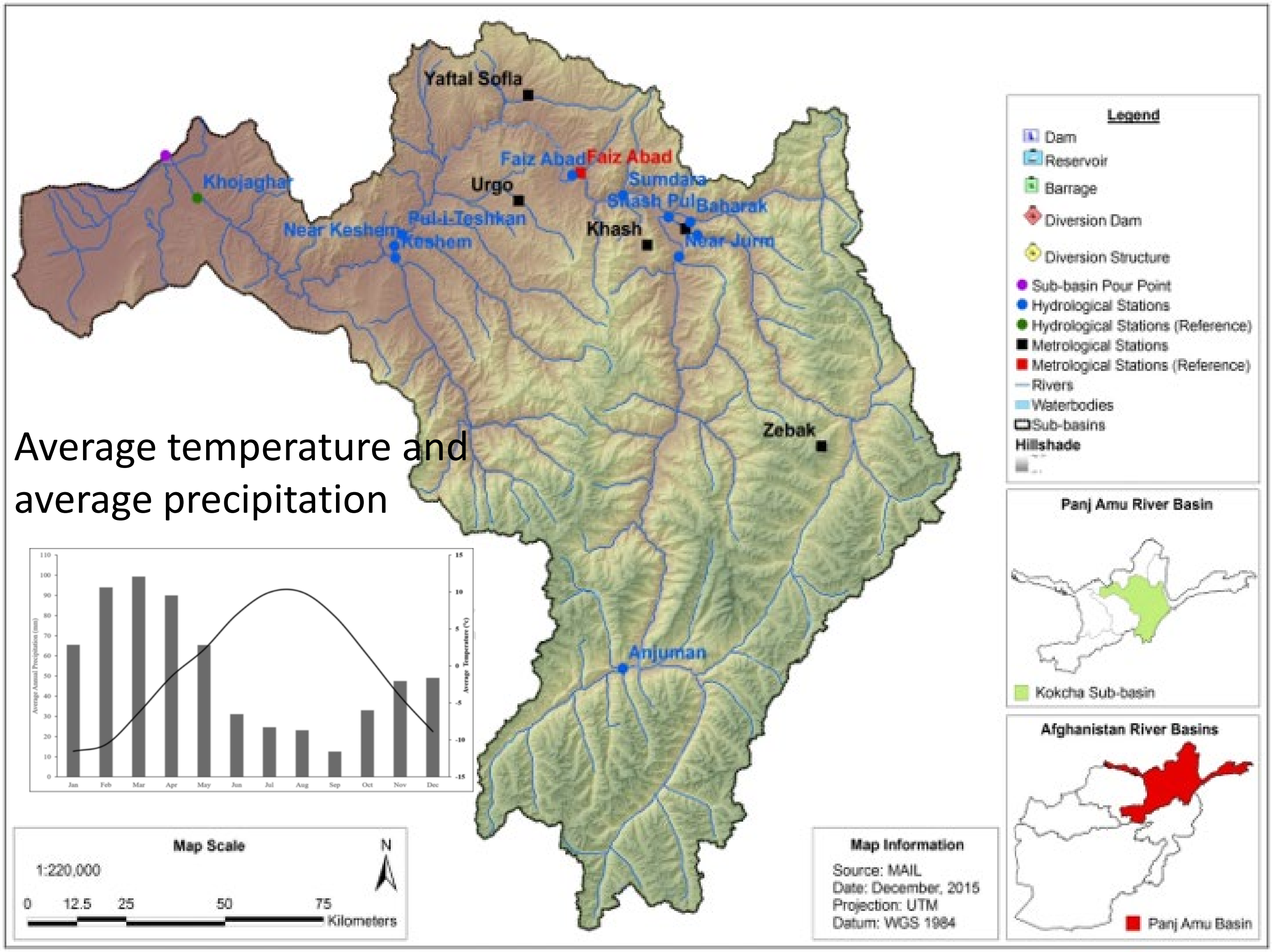
Study Area

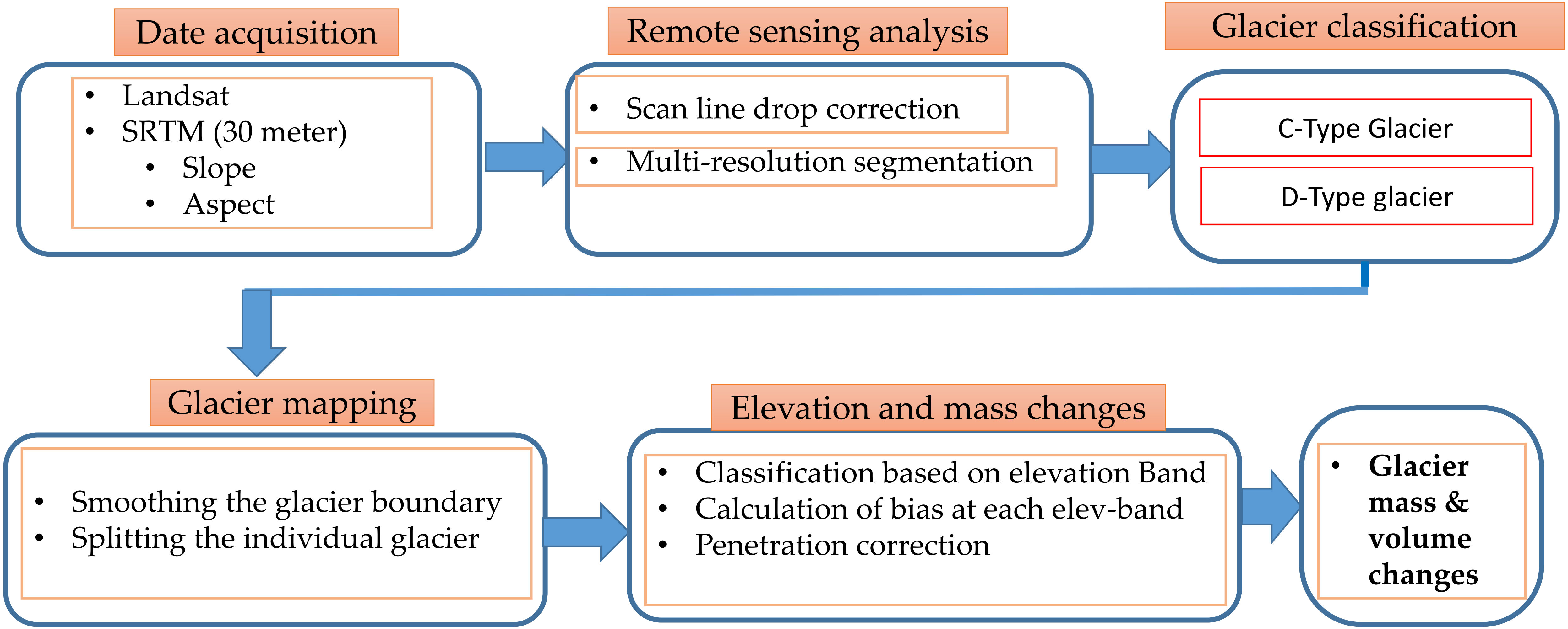
Kokcha sub-basin selected as the study area



The study area located in the northeast of Afghanistan, in the Hindukush mountain ranges.

- **The sub-basin covers an area of about 22,196 km^2.**
- **The mean elevation is approximately 4090 (m a.s.l.).**

Study framework



Resolution of the satellite data used in the study

Time	Path/Row	Satellite image	Sensor	Resolution (m)
2015	152034_152035	LC08_L1TP_152034_20160920_20170321 LC08_L1TP_152035_20150902_20170404	OLI	30
2010	152034_152035	LT_5152035_2010247 / LT_5152035_2011202	ETM+	30
2000	152034_152035	LT_5152035_2000236 / 152034_20010802	ETM+	30
1990	152034_152035	152034_19920918 / 152035_19920918	MSS	30

Glacier outline accuracy assessment

- 30m-resolution Landsat images with the least snow and no cloud cover were used for glacier delineation

- The total uncertainty (error) of the glacier area was calculated by the following formula

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(a_i - \hat{a}_i)^2}{n}}$$

- Where ai = Area of the glacier from glacier polygon and ai□= Area of the glacier calculated by pixel count.

- Accuracy assessment of the mass changes was calculated by considering the uncertainty in DEM differencing, radar signal penetration, uncertainty due to void fill, glacier outlines, and mass conversion and was estimated using equation

$$A = E_{\Delta h} + E_a + E_V + E_p + E_m$$

Eδh: is the error due to DEM difference in the off-glacier areas; Ea

is the change in the glacier-covered area; Ev is the uncertainty due to void fill, Ep and Em are the errors in the penetration and density assumptions.

Results: Glacier recession

- In total 1007 glaciers were mapped in the area during the year 1990. The size of the glaciers ranges from 0.02 to11.7 km2 with an average size of 0.57 km2 were identified
- The glacier area in the study area has significantly reduced from 576.77 ± 17.30 km2 in 1990 to 492.92 ± 9.85 km2 in 2015.

Year	Glacier Number	Area (km^2)	Area Change (km^2) 1990–2015
1990	1007	576.77 ± 17.30	
2000	1012	562.00 ± 11.45	14.77
2010	1003	551.15 ± 11.02	25.62
2015	998	492.92 ± 9.85	83.85

The Area has witnessed a loss of 83.85 Km2 (14.54%) glaciated area during he observation period

Results: Glacier lake inventory

- 162 glacial lakes were mapped in 1990 with the area ranging from 0.004 to 0.31 km2 covering an area of 6.42 km2. This number increased to 180 in 2015, with area ranging from 0.007 to 0.33 km2 covering an area of 8.12 km2.

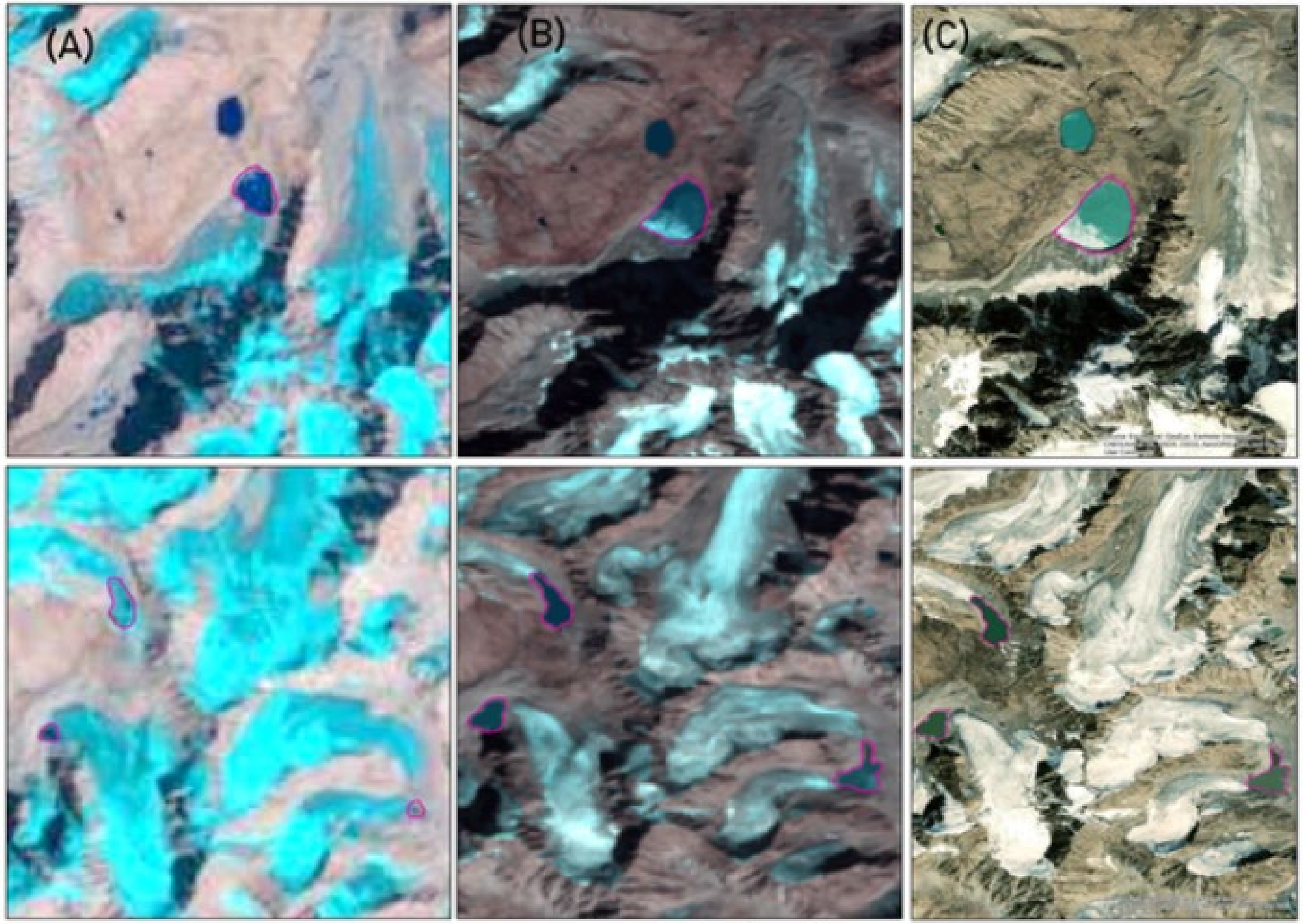


Fig. 4. Evolution of glacial lakes from 1990 to 2015 (A & B) and high-resolution map (C) of these glacial lakes in the Kokcha sub-basin.

Results: Influence of glacier size on recession

- **Influence of glacier size on recession**

The analysis showed that glaciers of class (1) have lost 10.4% of the area, while glaciers of class (2) have lost 11.03% of the area. Similarly, classes (3) and (4) have lost 47.42% and 5.31% of the glaciated area respectively during the observation period

Glacier class (size in km^2)	No. of Glaciers	Area Change (%) 1990–2015	Avg. Elevation (m)
0.02–1	861	10.04	5138
1–3	104	11.03	5048
3–5	16	47.42	5030
5–11	7	5.31	5353

Results: Impact of elevation on glacier recession

- The study reveal that glacier recession occurred mostly in the elevation range of 4300 to 5100 m a.s.l. Presently, most of the glaciers in the basin occur in the elevation ranges of 4800 to 5100 m a.s.l.
- It was further observed that glaciers occurring at lower elevations are showing a recession of 15.96%, while glaciers at mid and higher elevations are showing a recession of 12.97% and 97.56% respectively.

Results: Impact of elevation on glacier Elevation changes and mass loss

- Surface elevation changes of 127 (>1 km2) glaciers, which range between mean -7.2 and + 11.6 m/a estimated during the study
- The mass loss decreases towards the accumulation zones of the glaciers
- Smaller size of glaciers ranging in size from 1 to 3 km2 show an average mass change of -0.20 ±0.18 mw.e/a. larger size of glaciers from 3 to 5 km3 show an average mass changes of -0.25 ±0.18 m.w.e/a
- Glaciers ranging in size from 5 to 11 km2 show higher average mass changes of -36 ± 0.18 m

Area range (km^2)	Glacier number	MB (m w.e. a^{-1})	Min Elevation (m)
1–3	104	−0.20 ± 0.18	4664
3–5	16	−0.25 ± 0.18	4638
5–11	7	−0.36 ± 0.18	4373

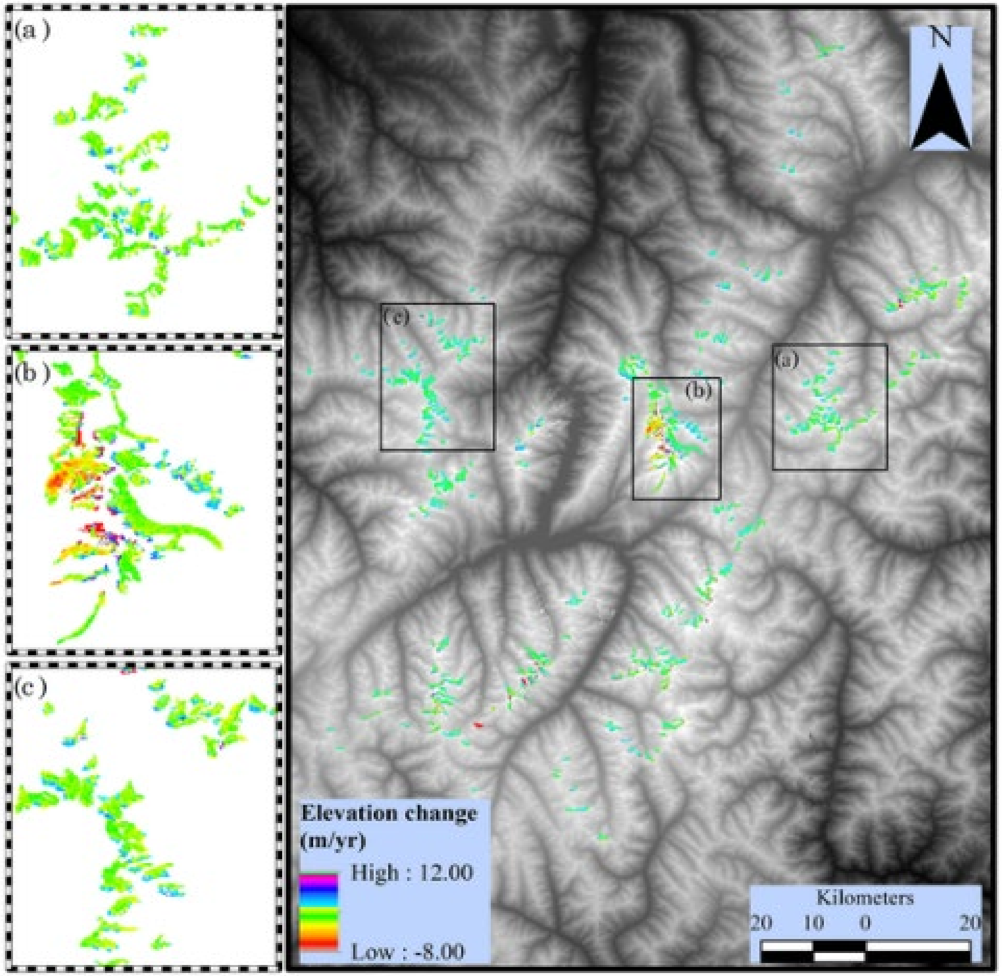
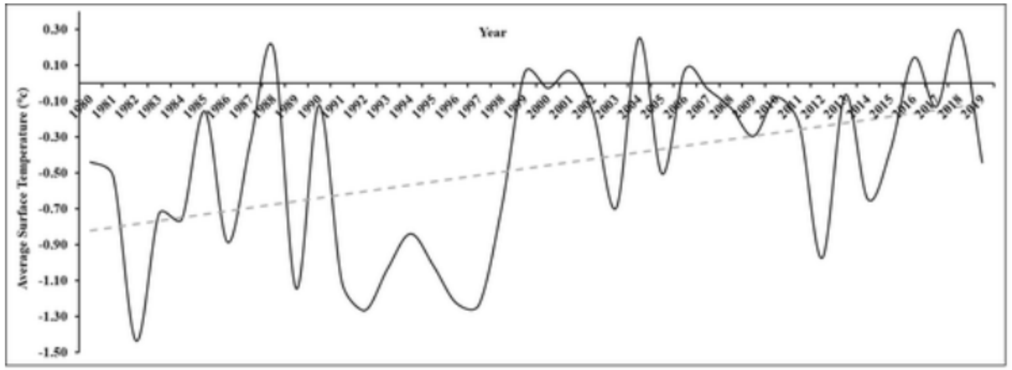
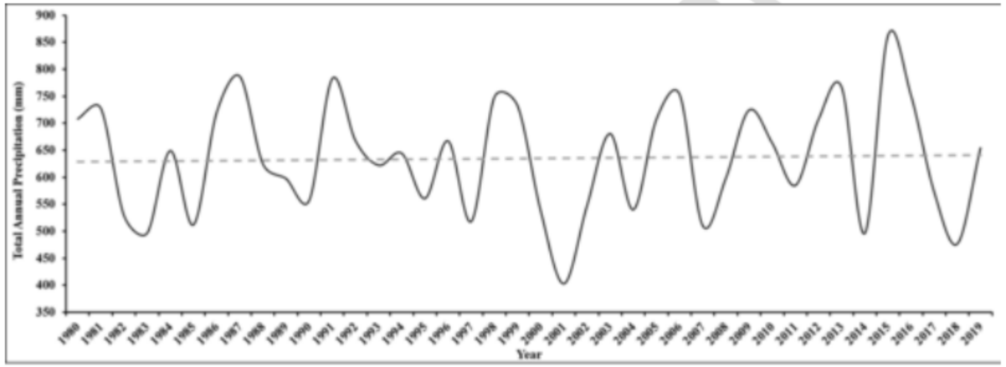


Fig. 5. SRTM DEM and TanXDEM derived glacier elevation changes in the Kokcha sub-basin from 2000 to 2012.

Results: Inferences from climate data analysis

- The interaction of climate and glaciers was assessed through the Mann-Kendall test on meteorological data of CRU (1980-2019)
- The analysis of mean annual temperature shows a statistically significant increasing trend ($p < 0.05$) and the Z statistic value was more than 2.57, which indicates the high significance of the increasing trend.
- It was assessed that increasing temperature during the period from 1998 to 2019 has resulted in significant glacier recession





Discussion

- This study and similar other studies in the HKH indicated that glaciers are receding in the region with spatial variability
- The observations of 25 years (1990 to 2015) revealed that glacier recession in the KB exhibits a complex pattern with size, elevation, and slope acting as dominant factors influencing the rate of glacier recession.
- Early disappearance of winter snow due to increasing (winter) temperature might have accelerated glacier melt by exposing the glacier surfaces to uninterrupted sunlight for longer periods.
- he overall analysis of the Landsat satellite data from 1990 to 2015 revealed that the glacier cover in the KB has reduced by 14.54%. From the year 1990 to 2015, more than ~84 km2 glaciated area, comprising 3.8 km3 ice reserves, were lost from the basin


THANK YOU