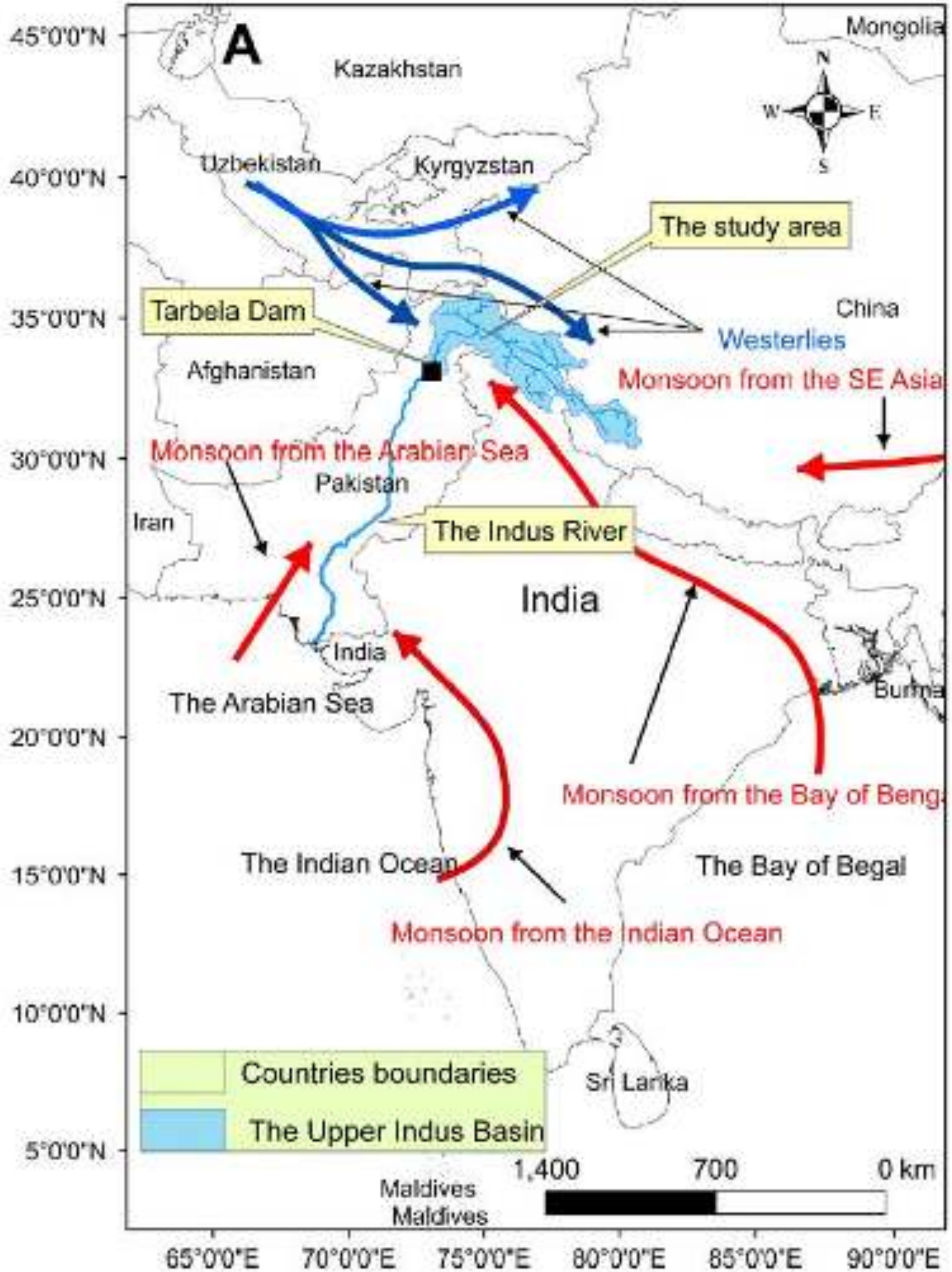
Recent Research in UIB

Hydrological working group

Outline

- UIB introduction
- Precipitation
- Snow cover
- Glacier
- Discharge



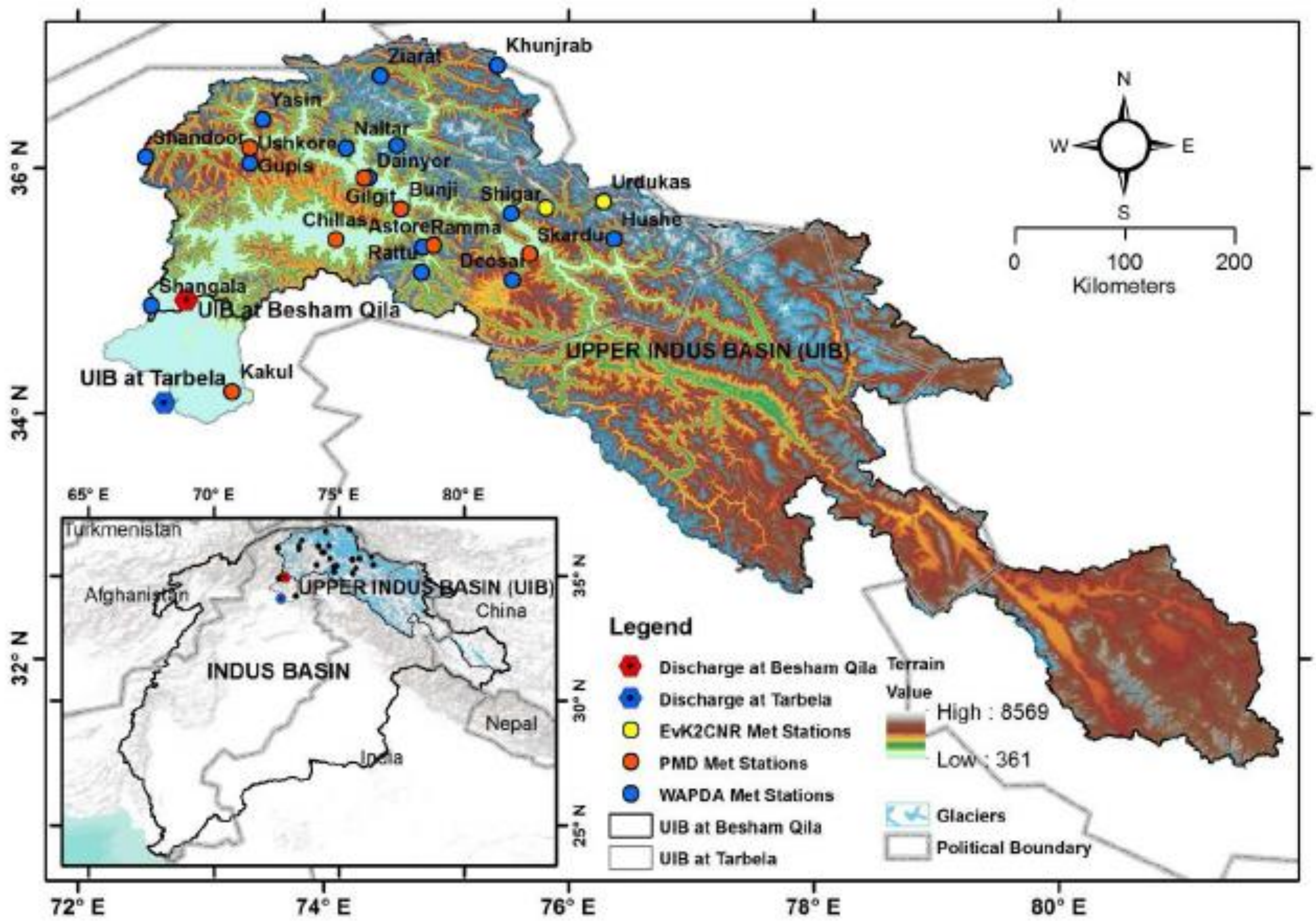
(Khan et al., 2015)

Upper Indus Basin (UIB)

- 15061.74 km^2 area
- 11413 glaciers

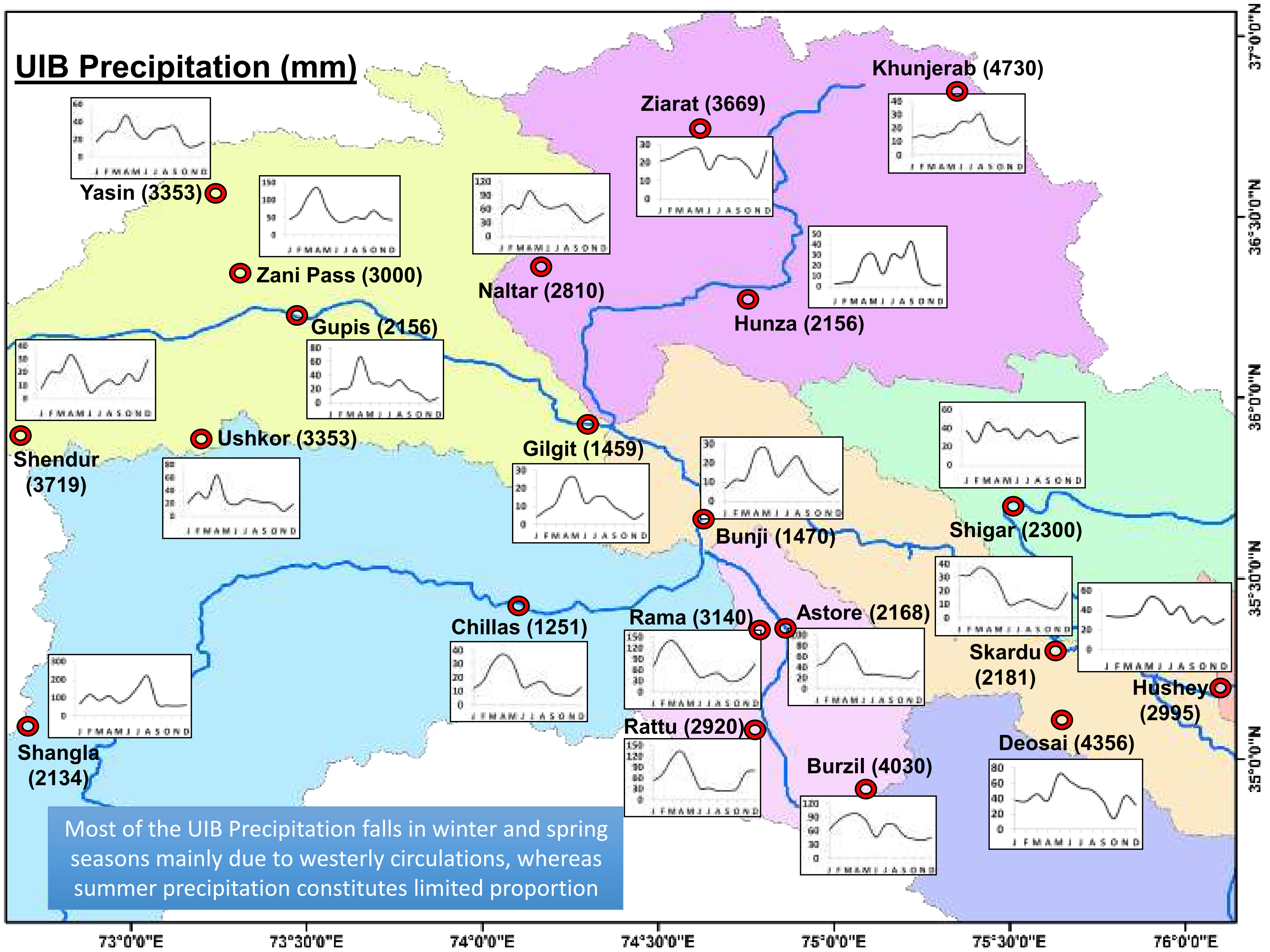
(Bajracharya and Shrestha, 2011)

- Delivering water for Pakistan
  - Agriculture
  - Drinking
  - Power production
- Third Pole
  - Climate Change



(Khan et al., 2015)

Precipitation

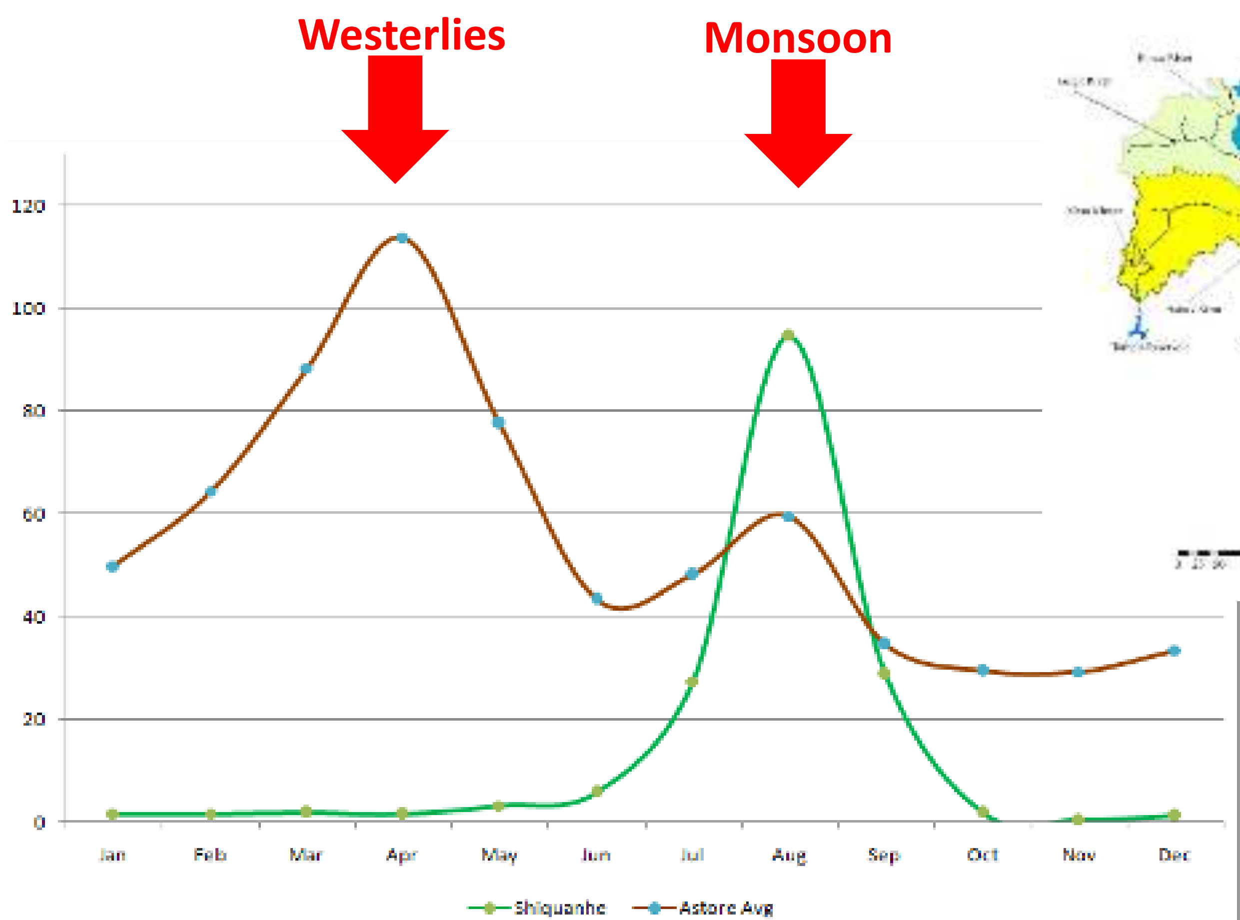


UIB Precipitation (mm)
Khunjerab (4730)
Ziarat (3669)
Yasin (3353)
Zani Pass (3000)
Naltar (2810)
Hunza (2156)
Gupis (2156)
Gilgit (1459)
Ushkor (3353)
Shendur (3719)
Bunji (1470)
Shigar (2300)
Chillas (1251)
Rama (3140)
Astore (2168)
Skardu (2181)
Hushey (2995)
Rattu (2920)
Deosai (4356)
Burzil (4030)
Shangla (2134)
Most of the UIB Precipitation falls in winter and spring seasons mainly due to westerly circulations, whereas summer precipitation constitutes limited proportion
73°0'0"E
73°30'0"E
74°0'0"E
74°30'0"E
75°0'0"E
75°30'0"E
76°0'0"E
37°0'0"N
36°30'0"N
36°0'0"N
35°30'0"N
35°0'0"N

Different Climate Conditions

- Astore by Westerly (~66% of Annual prec.)
- Shiquanhe by Monsoon (~90% of Annual prec.)
- Astore receives ≥850mm and Shiquanhe ≥200mm.

- Due to higher concentration of snow- & glacier-melt runoff, Astore stream-flow is highly sensitive to temperatures fluctuations as compare to Shiquanhe



1966-1995

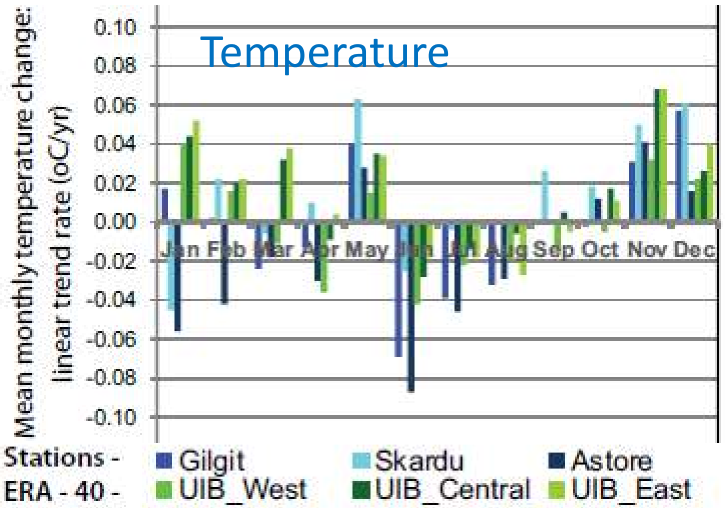


Fig. 3. Comparison of mean monthly temperature trends estimated using local observations and ERA-40 reanalysis data, common time period 1966–1995.

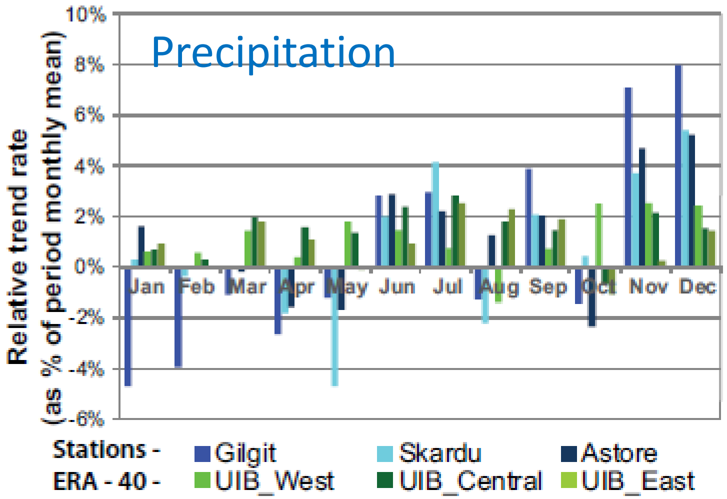


Fig. 4. Comparison of monthly precipitation trends using local observations and ERA-40 reanalysis data, 1966–1995.

(Sharif et al., 2013)

- Winter upward trends are concentrated in the early winter, limited change occurs from February to April (except Gilgit), whilst increases are displayed in June and July.

1995-2012

Trend of Precipitation

Tavg - average temperature
cooling (downward)
warming (upward)

P - precipitation
decrease (downward)
increase (upward)

(Hasson et al., 2015)

altitude ↓

Variable	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Ann.
P	Khunrab	**3.64**	2.59	-2.21	-1.55	-1.47	0.10	0.35	0.80	1.82	-1.04	0.93	2.34	**8.86**	-9.09	-1.74	1.65	6.14
	Deosai	0.07	1.28	**-1.42**	-0.66	-1.27	-0.89	-0.40	-1.00	-0.77	-0.42	-0.81	-0.32	1.40	-4.50	0.00	-1.99	-7.87
	Shendure	**1.54**	**2.75**	1.35	2.13	0.60	**2.12**	**1.83**	**1.38**	**1.45**	1.24	1.40	**2.20**	**5.71**	**4.50**	**4.82**	3.58	20.53
	Yasin	1.33	**1.86**	0.59	0.25	1.22	-0.50	**1.45**	0.02	0.92	-0.21	0.06	**2.74**	**6.09**	0.60	1.32	0.26	11.70
	Rama	0.77	0.00	-6.50	**-8.55**	**-4.52**	**-2.16**	**-2.35**	**-1.89**	**-1.44**	**-2.05**	-3.74	-2.03	7.00	**-25.44**	**-8.41**	**-14.60**	**-43.92**
	Hushe	0.65	0.24	-1.23	-0.30	-1.97	-1.21	-1.71	-0.60	0.73	-0.64	0.11	0.72	**3.47**	-4.51	-4.28	0.70	-5.54
	Ushkore	0.56	-0.59	**-2.33**	-1.02	-1.97	-0.93	0.00	-0.09	1.01	**-0.61**	-0.48	0.09	-0.13	-4.57	-1.54	-0.42	-3.83
	Ziarat	-0.91	-0.56	**-4.18**	**-5.28**	-1.83	0.25	-0.67	-0.18	**1.20**	-0.58	-0.43	-0.61	-3.59	**-9.10**	-1.71	-0.21	**-16.32**
	Naltar	3.75	4.41	-4.49	-0.36	-2.75	**-2.17**	0.43	-2.33	1.32	-0.36	-0.70	1.35	19.43	-8.39	-0.99	2.42	-0.28
	Rattu	**1.36**	**2.13**	0.08	0.36	0.26	0.53	**0.91**	0.75	**0.95**	**0.84**	**0.69**	**1.53**	**4.43**	1.23	1.81	**2.36**	10.64
	Shigar	-0.24	-0.89	-1.07	-2.62	-2.05	-0.33	1.75	0.80	**2.40**	1.13	0.18	1.49	-1.67	**-8.36**	0.78	**3.08**	-7.04
	Skardu	-0.64	1.62	0.60	0.19	-0.74	-0.47	-0.07	-0.44	0.46	0.00	0.00	0.20	0.41	0.89	-1.26	0.49	1.29
	Astore	0.00	0.41	0.12	**-1.41**	-0.48	-0.16	-0.08	-0.29	0.57	0.00	0.00	0.29	1.50	-1.36	-1.63	0.34	-0.16
	Gupis	0.65	**0.97**	**0.81**	0.38	-0.06	**-1.33**	**-1.07**	-0.49	0.06	0.35	0.26	**0.89**	2.81	0.29	**-3.49**	0.43	4.46
	Dainyor	-0.21	0.42	**0.51**	**0.55**	**0.67**	**1.24**	0.91	-0.71	-0.39	0.00	0.00	0.00	**1.68**	**1.81**	3.09	-0.34	6.69
	Gilgit	0.98	0.45	**-1.94**	-1.34	-1.57	-0.73	0.29	**-3.99**	0.32	0.00	0.00	0.30	0.00	**-9.39**	**-9.60**	-0.92	**-20.31**
	Bunji	0.01	-0.10	**-1.06**	**-2.34**	0.17	0.20	-0.34	-0.22	0.56	-0.01	0.00	0.11	-0.47	-2.68	-0.51	0.06	0.09
	Chilas	0.00	0.13	-0.14	-1.56	0.16	0.29	-0.51	0.13	**1.37**	-0.10	0.00	0.07	0.22	-0.81	-0.80	1.86	0.53

- Decrease in March-June period, a clear signal of dryness during the period March-June (spring month)
- Increase in winter season and September (last monsoonal month), signal of wetness;
- Higher in magnitude at high altitude stations compared to low altitude stations.

1960s-2012

Long-term Trend of Precipitation

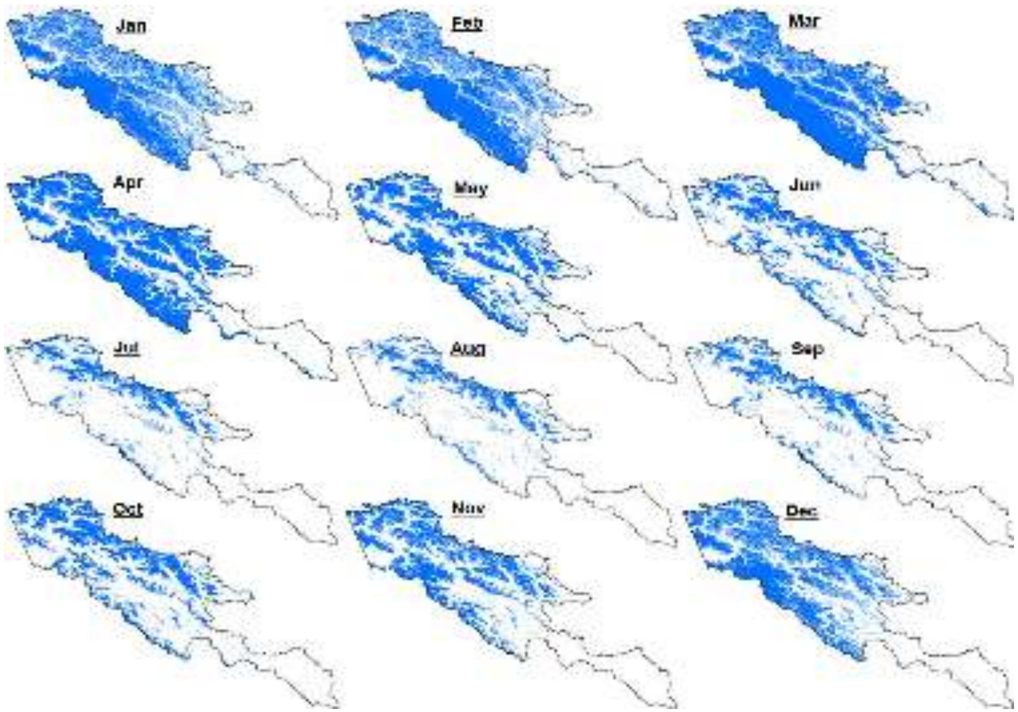
P - precipitation
decrease (downward)
increase (upward)

Variable	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Ann.
P	Skardu	**0.30**	0.32	0.16	0.16	-0.02	0.08	0.06	***0.19***	0.07	0.00	0.00	0.15	***0.98***	0.45	**0.29**	0.12	**1.76**
	Astore	0.00	-0.28	**-0.78**	-0.51	-0.25	0.27	**0.19**	0.06	0.02	-0.05	0.02	-0.08	0.24	-1.31	0.45	0.06	-1.33
	Gupis	**0.08**	0.04	**0.28**	0.30	-0.08	0.00	**0.24**	0.18	0.00	0.00	0.00	0.00	0.11	0.20	0.32	-0.09	2.00
	Gilgit	0.00	0.00	-0.02	0.05	-0.05	***0.23***	0.01	0.01	0.03	0.00	0.00	0.00	0.02	-0.44	0.28	0.10	0.38
	Bunji	0.00	-0.06	-0.14	0.02	-0.17	0.09	0.05	0.12	0.11	-0.03	0.00	0.00	0.13	**-0.59**	0.36	0.09	0.21
	Chilas	0.00	0.03	-0.12	0.00	-0.01	**0.10**	0.07	0.07	***0.07***	-0.02	0.00	0.00	0.25	-0.12	***0.51***	0.03	0.70

(Hasson et al., 2015)

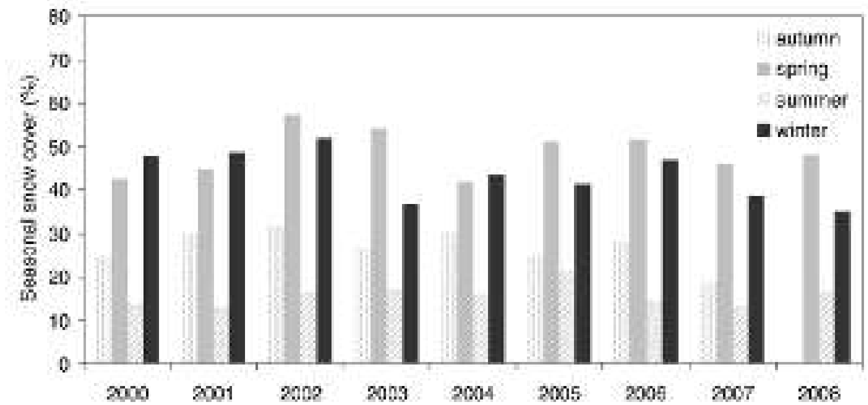
- Shifts in the summer month (June - August)
  - Recent decades (1995-2012): drying trend
  - Long-term (all record year): wetting trend
  - May attribute to multi-decadal variability that is associated with the global indices (i.e., NAO and ENSO)
- Consistent increase in September precipitation for both long-term trend and trend obtained over 1995-2012 at low altitude stations.

Snow cover



UIB Mean Monthly Snow Cover (2003-2010)

(unpublished)



Seasonal snow cover from 2000 to 2008 based on MODIS MOD10C2 product for UIB

(Immerzeel et al., 2009)

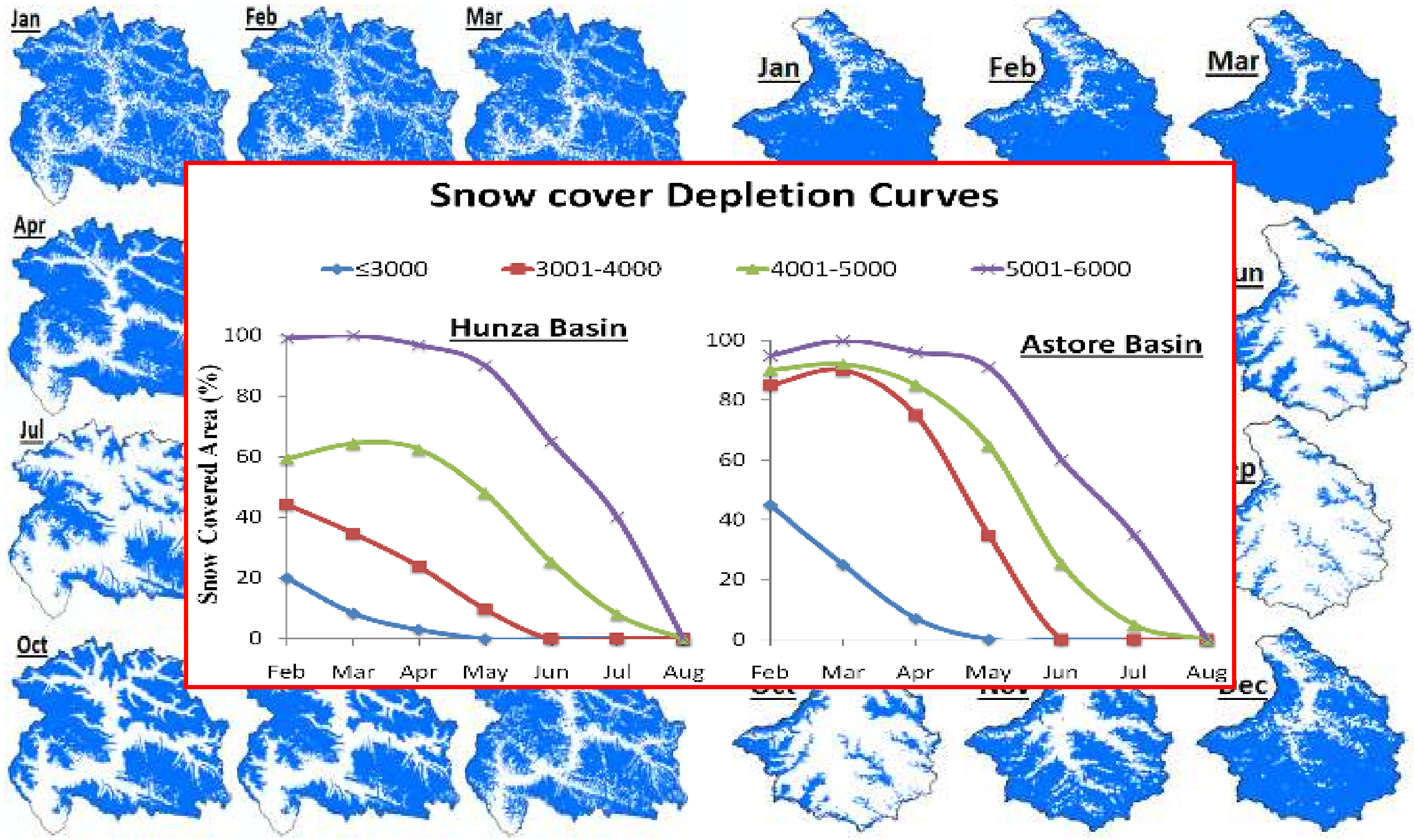
Pearson correlation coefficients for seasonal trends in snow cover UIB and the three elevation zones Zone 1 (2000 m), Zone 2 (4700 m), Zone 3 (5000 m)

	Upper Indus	Zone 1	Zone 2	Zone 3
Spring	0.10	−0.13	−0.02	0.20
Summer	0.22	0.17	0.22	0.21
Autumn	−0.47	−0.44	−0.56	−0.16
Winter	**−0.68**	0.29	**−0.64**	**−0.78**
Annual	−0.30	−0.14	−0.47	−0.19

- **Snowfall started at the month of September**
- **Maximum snow-cover reaches in Mar-Apr month**
- **Seasonal snow cover reaches 50-60% of the basin area**
- **Snow-melt period starts in late March or early April**
- **Most of the snow melted away be the end of August**
- **Significant negative trend for winter snow cover**

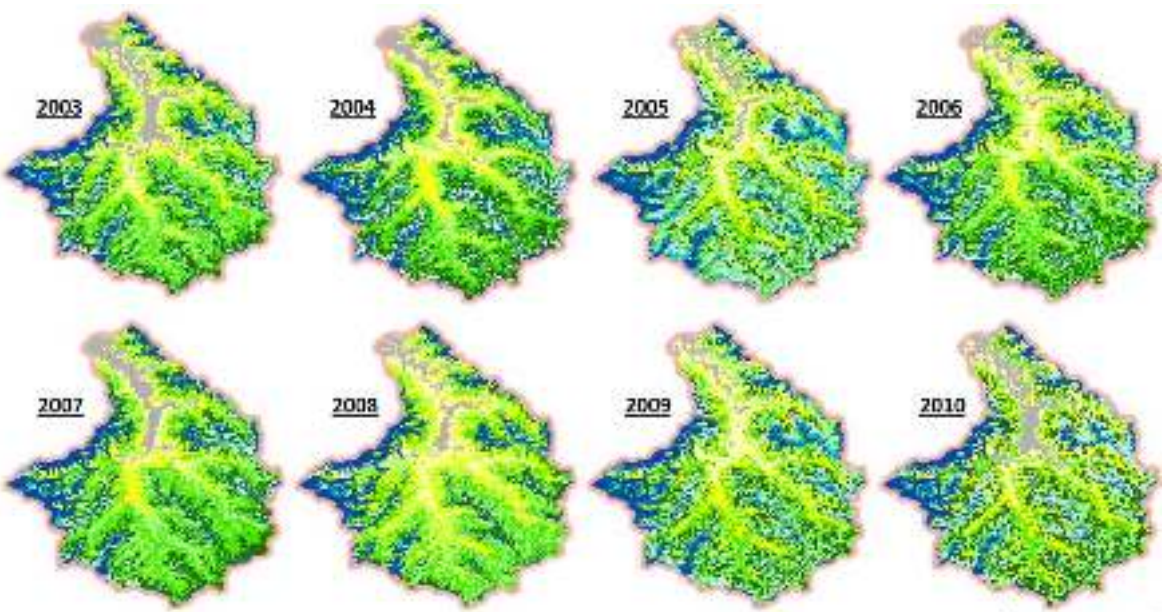
Snow Cover Change in Astore and Hunaz Basin

Hunza Basin | **Astore Basin**

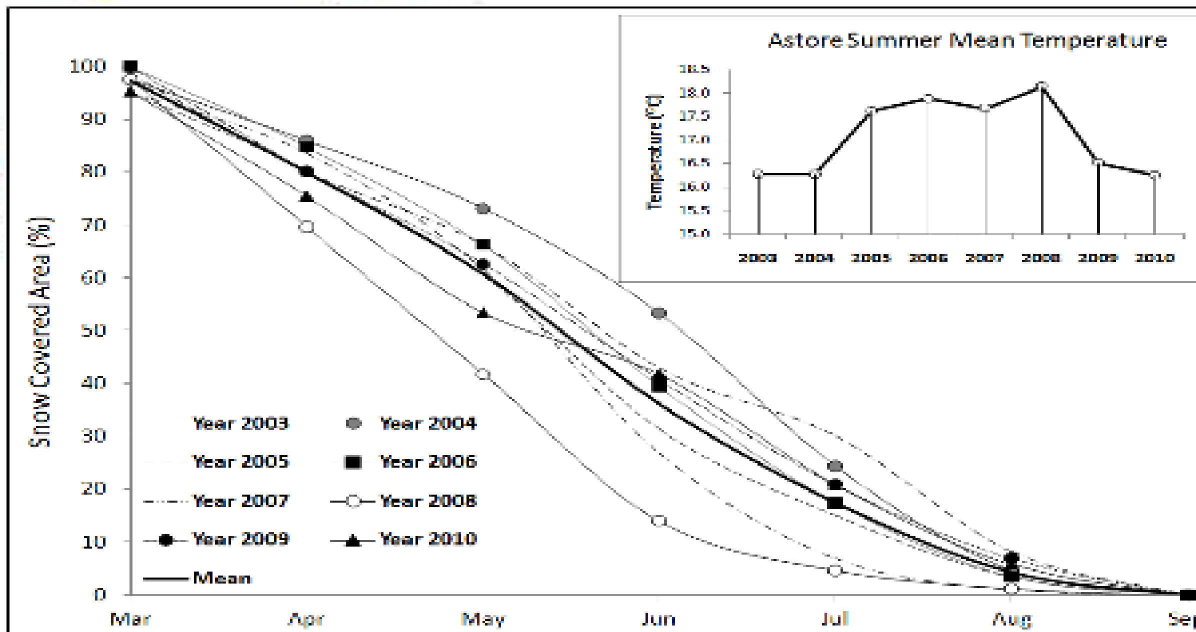


(unpublished)

Astore basin Snow Cover Duration and Depletion Timings

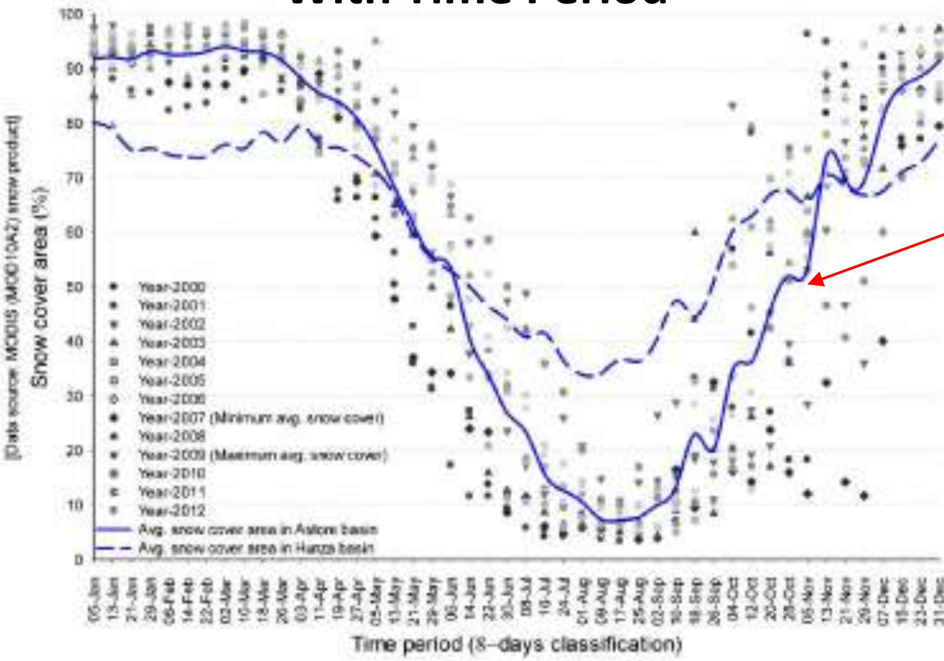


No much variation found in inter-annual snow cover depletion. However, the snow residual period was highest in 2004 , and lowest in 2008 due to temperature variation



(Farhan S, et al., 2014)

Snow Cover Area Change With Time Period



(Tahir A, et al., 2011, 2015)

	Astore River basin	Hunza River basin
Snow cover area:		
Annual snow cover area spatial variation	7–95%	30–80%
Snow cover trend over 13-years (2000–2012): (Kendall's tau (τ) coefficient value)	τ = +0.03	τ = +0.02
Snow cover trend on snow accumulation periods (December to February)	τ = +0.06	τ = +0.25
Snow cover trend on snow melt periods (July to September)	τ = +0.07	τ = +0.01
Correlations (annual):		
Q vs SCA	−0.56	−0.89
Q vs T_{avg}	+0.75	+0.85
Q vs P	−0.28	+0.08
P vs SCA	+0.52	−0.07
SCA vs T_{avg}	−0.89	−0.80
Snow cover area	Constancy/ slight increase	Constancy/ slight increase

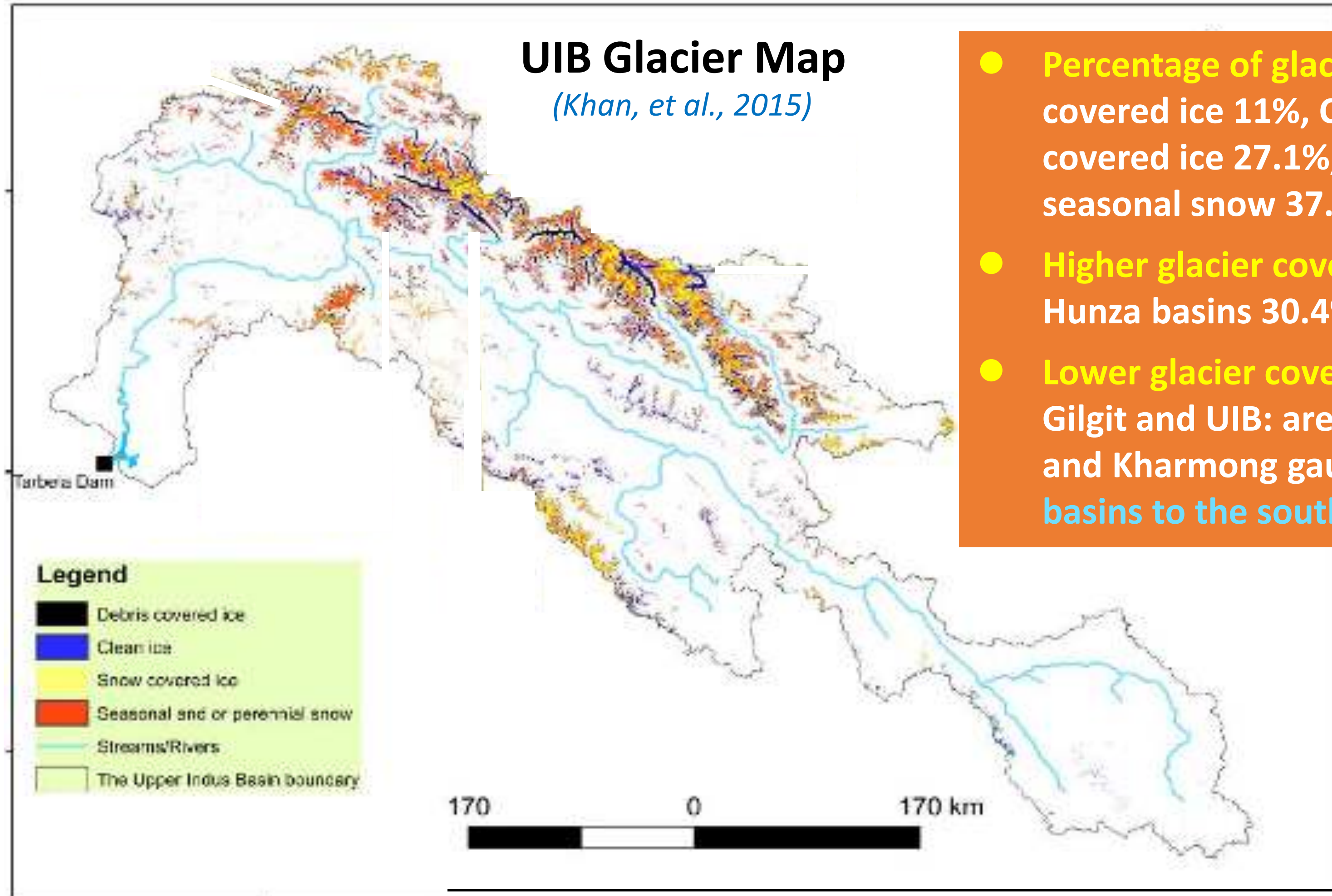
- The snow accumulation period starts in October and the maximum snow cover reaches a range of 90–95% (Astore) and 75-80% (Hunza);
- The snowmelt period starts in early April and the minimum snow cover is observed during August and September when the snow cover drops to a range of 5–10% in Astore and 35-40% in Hunza

- Snow cover area with the constancy or slight increase trends in

Glacier

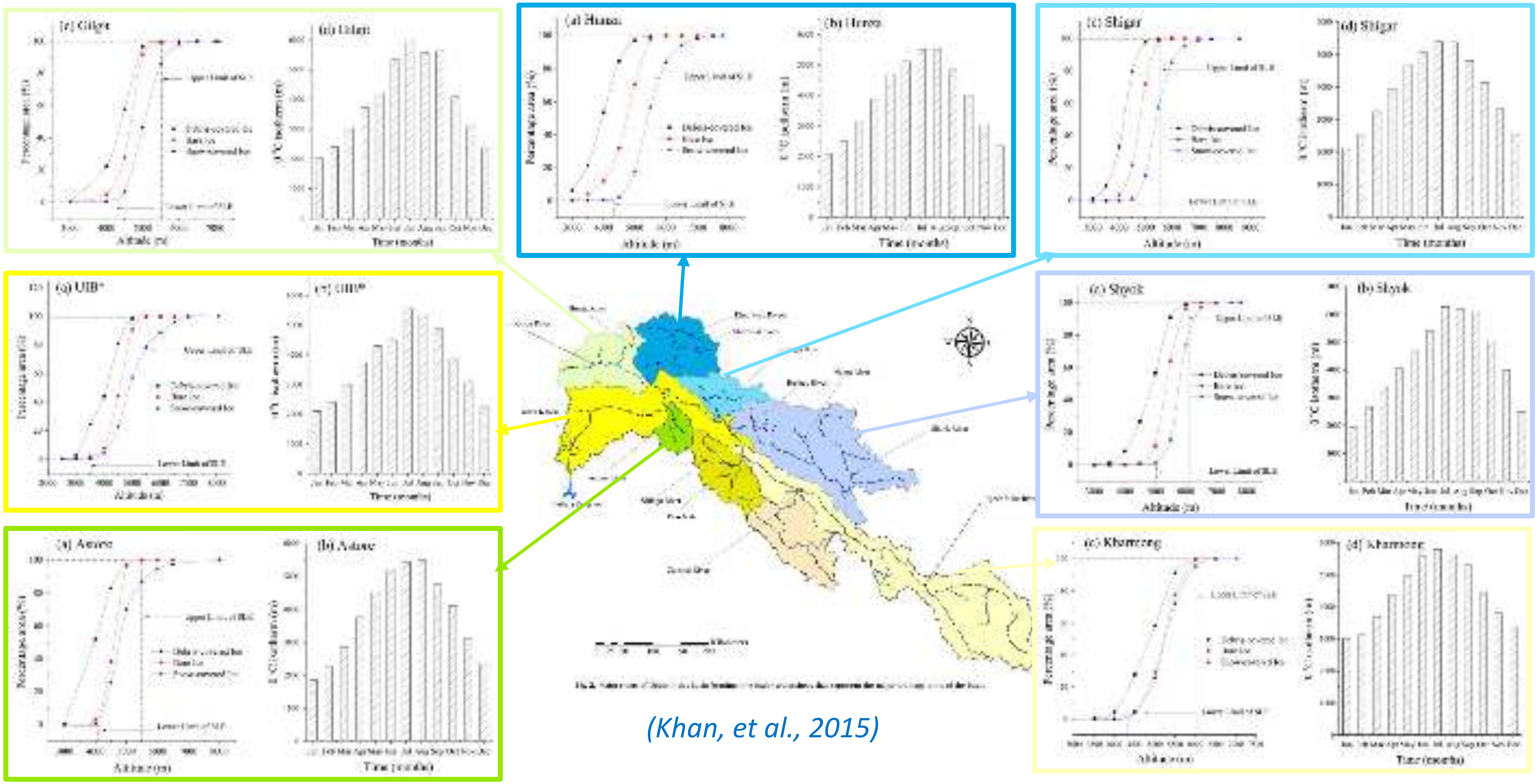
UIB Glacier Map

(Khan, et al., 2015)



- **Percentage of glacier area**: Debris-covered ice 11%, Clean ice 24.3%, Snow-covered ice 27.1%, Perennial and seasonal snow 37.5%
- **Higher glacier cover**: Shigar basins 38.9%, Hunza basins 30.4%, Shyok basins 25%;
- **Lower glacier cover**: Kharmong, Astore, Gilgit and UIB: area between Tarbela Dam and Kharmong gauging station (the sub-basins to the south)

Unit: km^2	Kääb et al. (2012)	Snow–glacier Total	Glacier[1]	Debris-covered ice	Clean ice	Snow-covered ice	Perennial and seasonal snow***
Gilgit	1360 ± 136	1091 ± 109	686 ± 69	147 ± 14	302 ± 30	237 ± 23	405 ± 23
Hunza	3774 ± 377	4151 ± 415	2194 ± 219	479 ± 48	811 ± 81	904 ± 90.4	1957 ± 196
Shigar	2671 ± 267	2738 ± 273	1735 ± 173	415 ± 41	656 ± 65	664 ± 66	1003 ± 100
Shyok	7871 ± 787	7372 ± 737	4991 ± 499	704 ± 70	1825 ± 182	2462 ± 246	2381 ± 238
Kharmong	2315 ± 231	2254 ± 225	1592 ± 159	224 ± 22	786 ± 78	553 ± 55	691 ± 69
Astore	299 ± 29	479 ± 48	247 ± 25	45 ± 4	52 ± 5	150 ± 15	232 ± 23
UIB**	974 ± 97	1199 ± 119	630 ± 63	112 ± 11	263 ± 26	256 ± 26	569 ± 57
Total	19,264 ± 1926	19,285 ± 1928	12,075 ± 1207	2126 ± 212	4695 ± 469	5226 ± 522	7238 ± 724



(Khan, et al., 2015)

- Equilibrium Line Altitude (ELA) estimates based on the Snow Line Elevation (SLE) in various watersheds range between 4800 and 5500 m, while the Accumulation Area Ratio (AAR) ranges between 7% and 80%.
- 0 °C isotherms during peak ablation months (July and August) range between 5500 and 6200 m in various watersheds

Estimates of ELA, AAR, maximum 0 °C isotherms, and other studies' ELA and AAR values.

Watershed	SLE/ELA (m)	AAR (%)	Maximum 0 °C isotherm (m)	Hewitt (2011, 2013)	Hasson et al. (2013) (m)
Gilgit	4250–5500 (4850)	21–65% (43%)	5970		3900–4000
Hunza	4300–5520 (5000)	25–43% (34%)	5515	4800–5200 m (22–40%)	3400–3500
Shigar	4500–5550 (5050)	21–51% (36%)	5398	4800–5600 m (4–37%)	3800–3900
Shyok	5020–6030 (5500)	22–65% (44%)	6263	5200–6000 m (29–60%)	4200–4300
Kharmong	4300–6000 (5250)	7–80% (44%)	5793		3200–3300
Astore	4100–5500 (4700)	20–75% (48%)	5500		4100–4200
UIB[**]	3550–5550 (4700)	17–51% (34%)	5500		

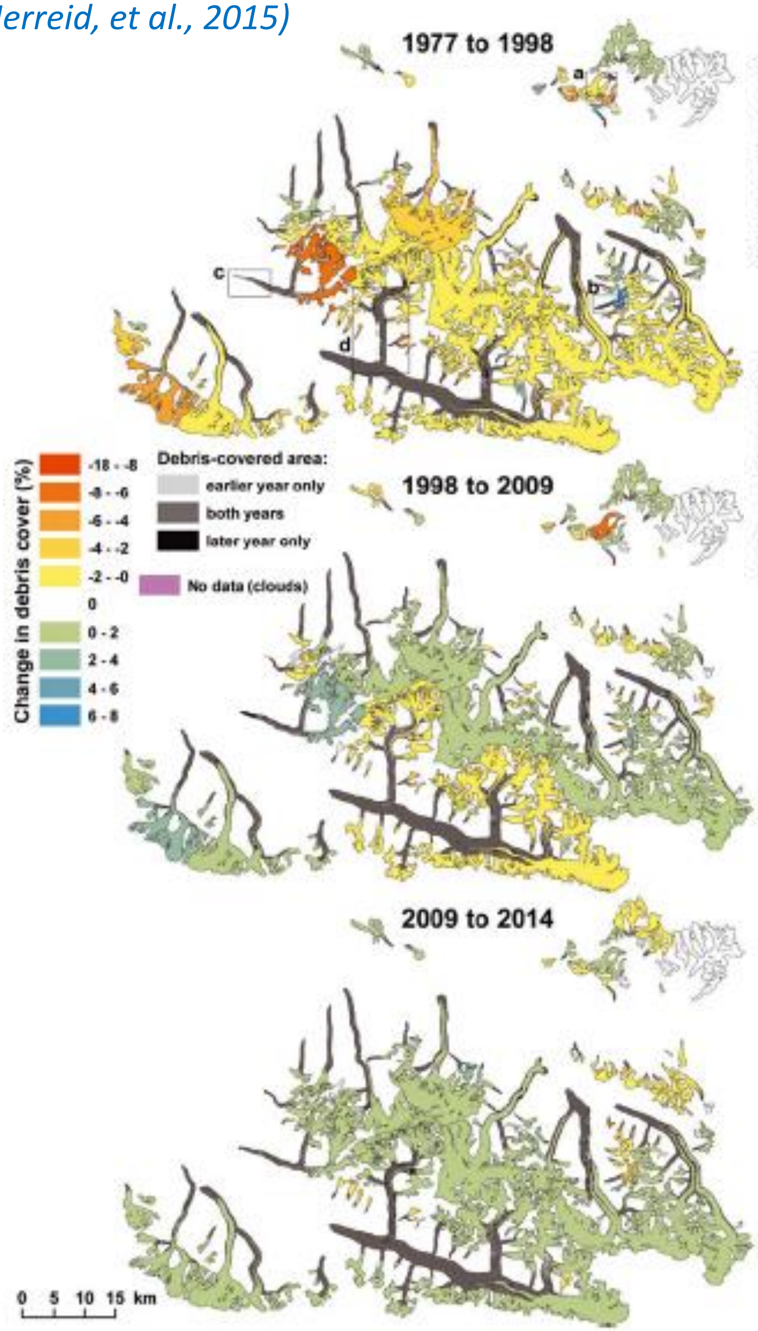
Watershed	Gardelle et al. (2013)	Kääb et al. (2012)	Scherler et al. (2011) (m)	Other studies (m)
Gilgit	4890–5210 m (30%)	30%	5140	5050
Hunza	4750–5310 m (66–76%)	5540 m (47%)	4884	4700–5300
Shigar				4800–5200
Shyok				
Kharmong		32%		5200–5800[1]
Astore				3750–5200[2]
UIB[**]				
Western Himalayas	5407–5806 m (34%)		5102	4800–5700

(Khan, et al., 2015)

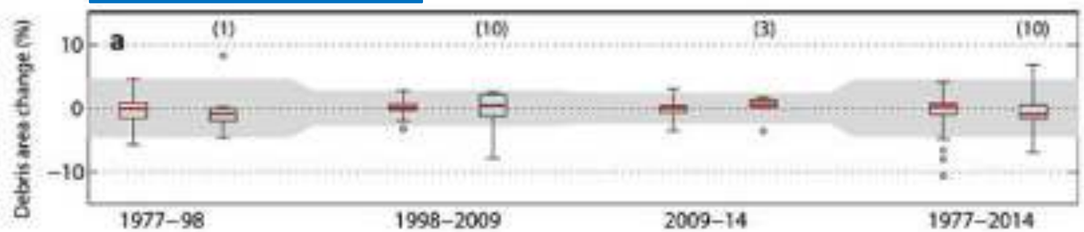
- the ELA and AAR values in the Karakoram region (the western Karakoram; Hunza and Shigar watershed) are far different from western Himalayan glaciers (Kharmong watershed, and other studies).

Supraglacial debris-cover area change

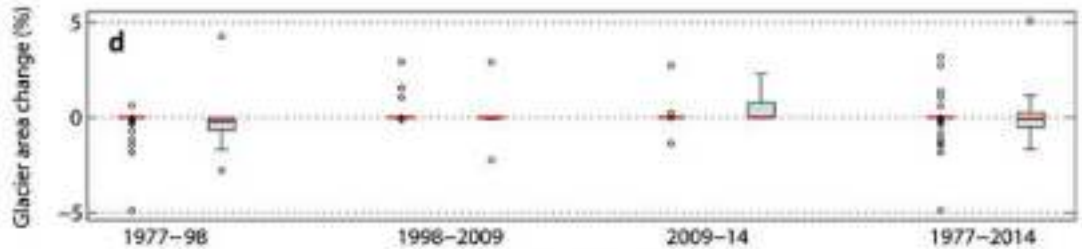
(Herreid, et al., 2015)



Debris area change



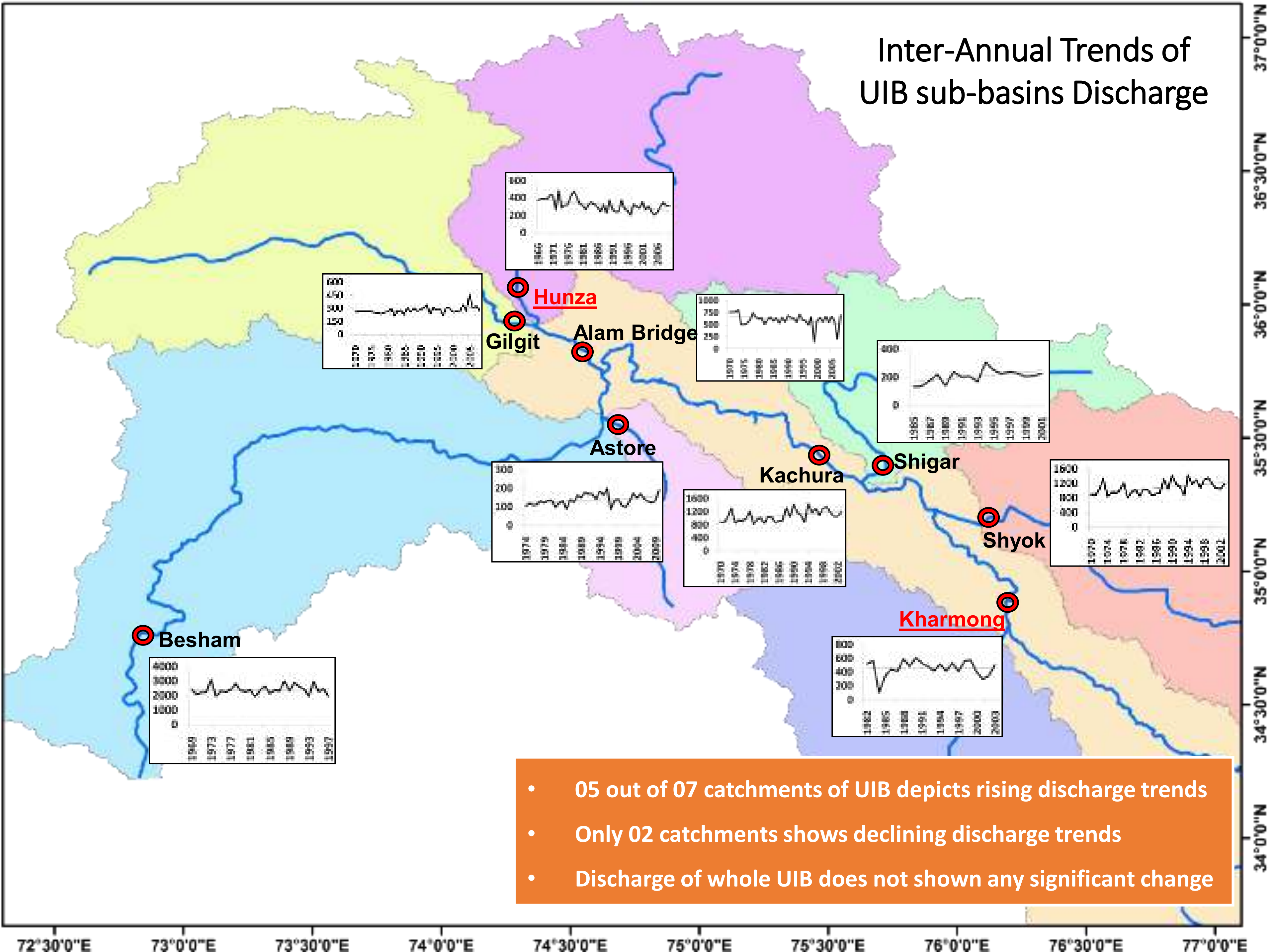
Glacier area change



Box plots: First for no-surge-type, second for surge-type glaciers

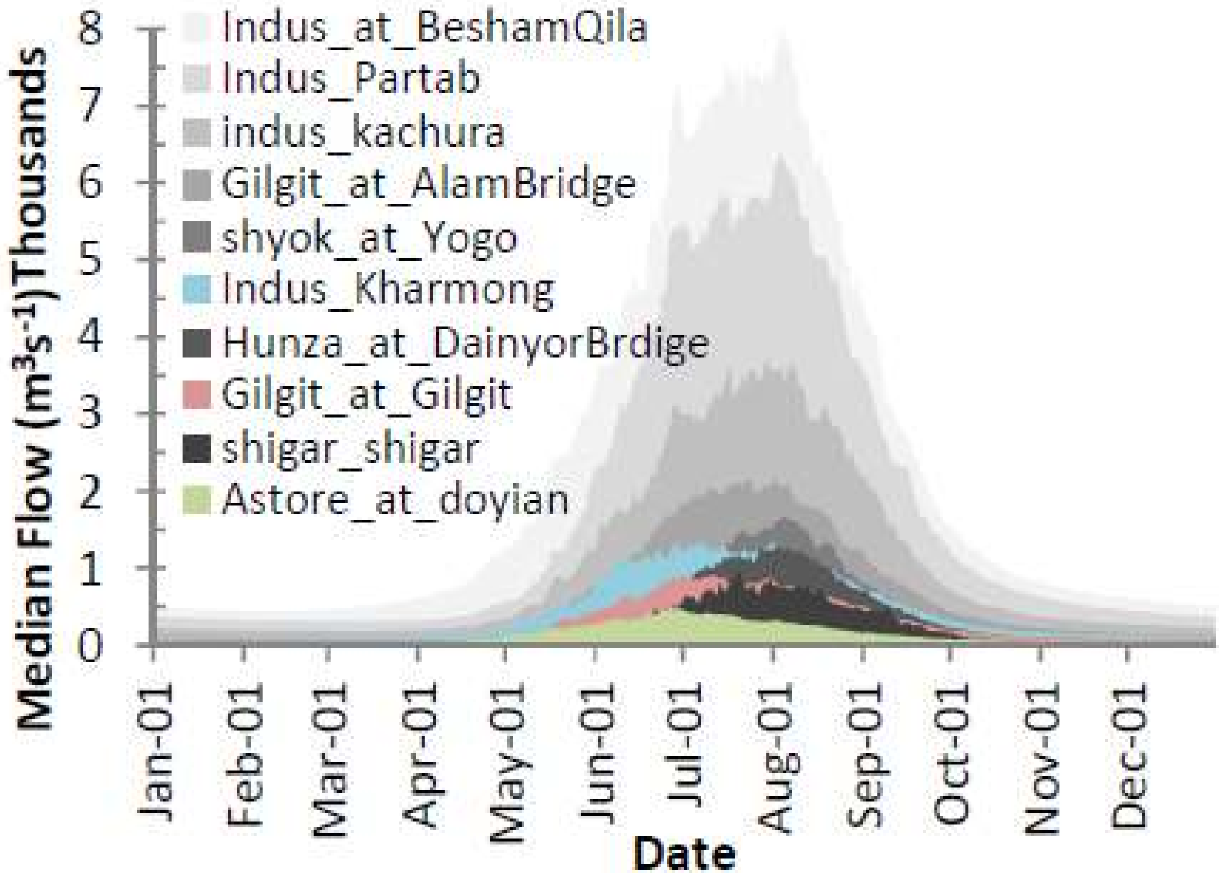
- **Surge-type glaciers occupy 41%**
- **The time series of debris-covered surface area change shows a mean value of zero or nearzero change for both surging and non-surging glaciers.**
- **An increase in debris-covered area is often associated with negative regional mass balances.**
- **Stable regional mass balances in the Karakoram explain the zero or near-zero change in debris-covered area. This**

Discharge/runoff


Inter-Annual Trends of
UIB sub-basins Discharge
Hunza
Gilgit
Alam Bridge
Astore
Kachura
Shigar
Shyok
Kharmong
Besham
• 05 out of 07 catchments of UIB depicts rising discharge trends
• Only 02 catchments shows declining discharge trends
• Discharge of whole UIB does not shown any significant change
72°30'0"E
73°0'0"E
73°30'0"E
74°0'0"E
74°30'0"E
75°0'0"E
75°30'0"E
76°0'0"E
76°30'0"E
77°0'0"E
37°0'0"N
36°30'0"N
36°0'0"N
35°30'0"N
35°0'0"N
34°30'0"N
34°0'0"N

Long-term median hydrograph (Seasonal Change)

(Hasson et al., 2015)



- Indus at Kharmong (Eastern UIB), Gilgit at Gilgit (Hindukush) and Astore at Doyian are primarily snow fed basins, generally featuring their peak runoff in July. (show in color)
- The rest of the basins are mainly glacier fed basins that feature their peak runoff in August. (show in gray shades)

Spatial distribution of discharge trend

1960-1998

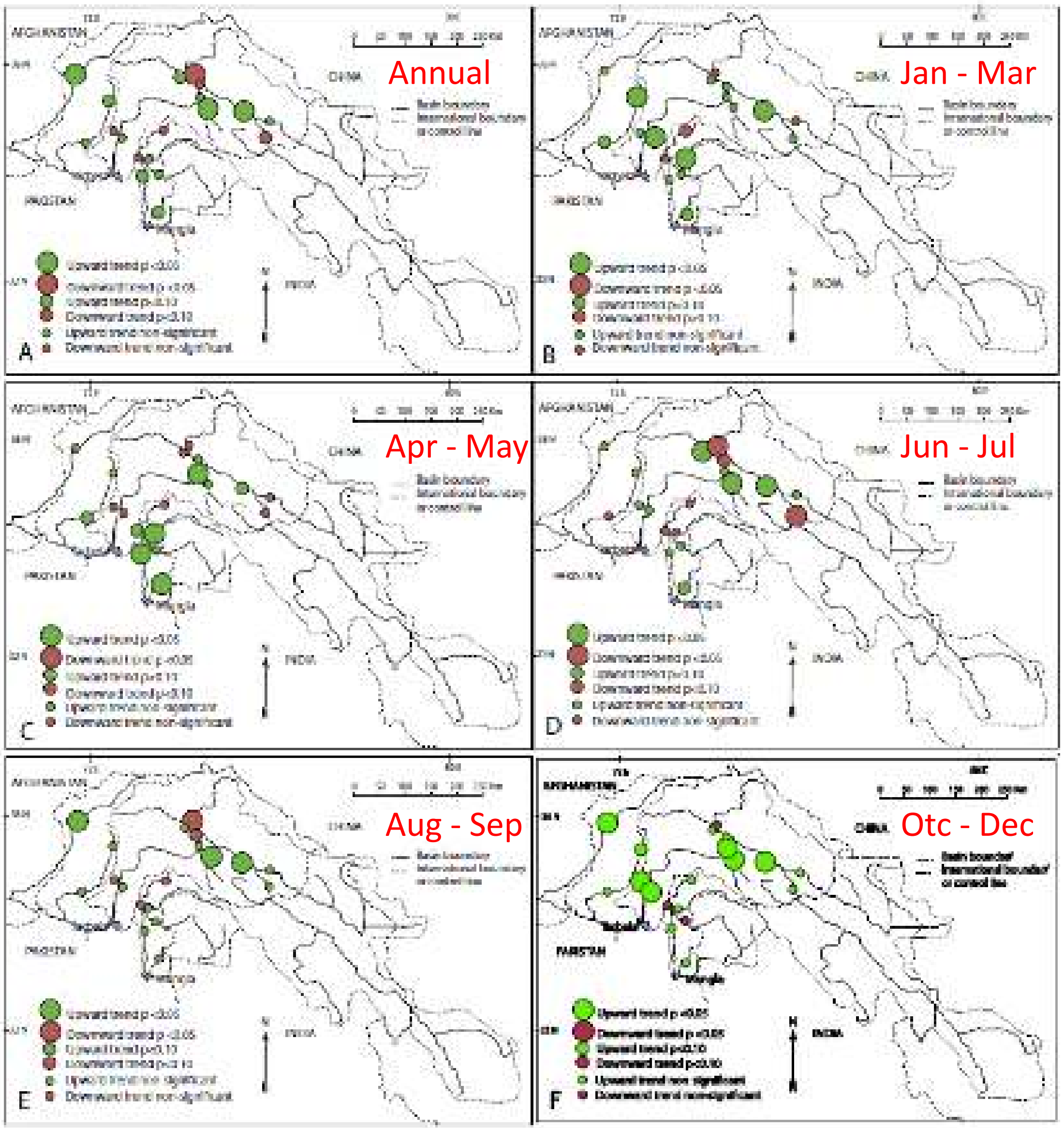


Fig. 5. Spatial distribution of trends in annual and seasonal flow magnitude. (A) annual trend, (B) January–March trend, (C) April–May trend, (D) June–July trend, (E) August–September trend, (F) October–December trend.

1995-2012

Trend of Discharge

Q - discharge

increase

decrease

(Hasson et al., 2015)

altitude ↓

Variable	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Ann.
Q	UIB-East	***-0.80***	0.00	0.04	0.11	-4.19	2.00	-1.65	6.70	-4.74	-5.45	***-2.46***	**-1.37**	***-0.75***	-2.64	-2.62	-0.86	-1.73
	Eastern-Karakoram	0.06	0.08	-0.10	0.00	1.96	0.96	**-22.97**	0.92	-8.84	-1.06	0.50	-0.09	0.29	0.67	0.30	-4.41	-0.95
	Central-Karakoram	0.96	1.28	1.56	-0.84	3.74	-8.94	***-37.93***	-9.08	-5.98	0.71	2.50	***2.76***	1.13	1.13	-21.61	1.10	-1.56
	Kachura	0.33	1.39	**1.06**	-0.33	-2.08	-22.50	**-50.04**	-16.74	-4.25	-2.18	0.59	2.64	0.46	-0.81	-18.90	-2.63	-4.97
	UIB-Central	**2.19**	1.81	2.02	-0.84	6.89	-18.08	***-43.79***	-20.20	-4.88	1.05	***4.38***	***2.34***	**2.00**	1.79	-18.34	2.01	-2.47
	Western-Karakoram	1.20	1.00	1.50	***2.00***	0.59	12.09	-4.53	-4.09	**6.40**	***3.50***	***3.82***	***2.03***	***1.88***	1.00	-1.64	***5.43***	2.50
	Karakoram	1.88	2.00	1.33	1.00	-5.82	-7.80	**-64.97**	-37.17	-9.48	0.60	***8.97***	***5.97***	***1.65***	0.11	-24.43	5.64	-3.90
	Hindukush	0.87	0.26	0.15	1.27	2.05	3.49	-6.61	**14.02**	**7.03**	2.17	1.82	1.06	0.75	1.00	3.94	4.44	4.00
	UIB-WU	1.24	**1.02**	1.39	**2.38**	***16.85***	12.38	-25.48	-15.50	-1.28	0.69	0.98	0.52	0.55	***7.76***	-3.68	0.45	-1.25
	Astore	0.05	0.00	0.22	0.50	7.65	4.26	-3.01	5.00	-1.00	-1.11	-0.67	0.00	0.00	2.20	1.97	-0.89	2.16
	Partab_Bridge	1.00	-0.13	3.60	8.80	63.22	-34.86	-39.86	-67.33	29.65	0.69	8.89	15.12	8.40	36.29	-67.00	9.81	-12.40
	UIB-WL	1.88	0.41	6.39	-0.52	41.58	**59.50**	28.19	***81.58***	**30.99**	16.18	5.17	2.33	1.92	19.90	***65.53***	***16.02***	***25.44***
	UIB-WL-Partab	-3.00	0.80	-4.38	-0.82	***87.89***	51.53	9.00	17.67	2.71	-12.24	1.40	-6.00	-3.74	28.32	47.93	-3.00	18.94
	UIB_West	2.45	1.37	5.43	2.42	**61.35**	54.89	0.21	42.93	***28.24***	**13.68**	***5.87***	1.38	2.00	**23.43**	44.18	***17.71***	***22.17***
	Himalaya	0.30	-0.32	4.10	0.91	43.99	62.23	12.43	83.33	22.43	9.97	2.32	0.23	1.17	26.64	**57.88**	7.75	***24.66***
	UIB	1.82	***5.09***	5.37	-2.50	11.35	14.67	-46.60	41.71	35.22	10.17	5.29	0.75	1.91	15.72	-1.40	19.35	4.25

- During winter, spring and autumn seasons, discharge at most sites increases while during summer season and on an annual time scale there is a mixed response.
- Most of the hydrometric stations experience a decreasing trend of discharge during the month of July, owing to drop in July temperatures, which are mainly in high-altitude/latitude glacier-fed regions;
- regions showing an increase in discharge during September are mainly the western region of UIB

1960s-2012

Trend of Discharge

Q - discharge

increase

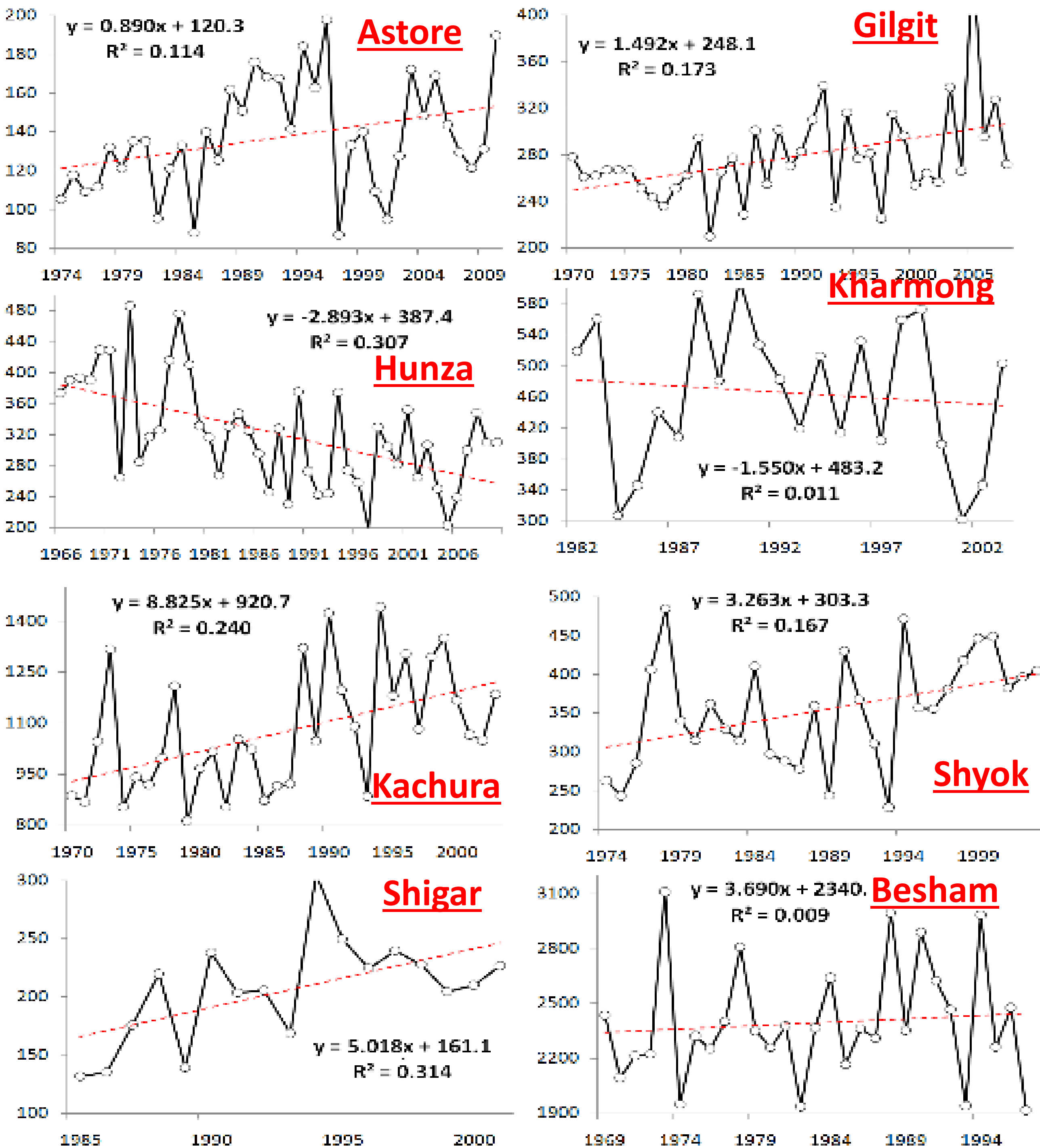
decrease

(Hasson et al., 2015)

altitude ↓

Variable	Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Ann.
Q	UIB-East	0.58	0.89	1.18	0.80	0.08	-12.94	-21.37	-10.53	-1.42	-0.18	0.06	0.16	0.55	1.10	-14.86	-0.57	-1.59
	Eastern-Karakoram	0.00	0.00	-0.04	-0.08	1.79	6.46	5.17	6.81	4.34	1.31	0.24	0.00	0.07	0.41	7.08	2.05	2.43
	Central-Karakoram	0.32	-0.07	-0.51	-0.67	6.13	3.85	-1.22	6.30	-7.40	-4.08	-1.36	-0.29	-0.35	1.75	6.22	-2.80	0.31
	Kachura	1.04	1.40	1.19	0.43	6.06	12.88	14.75	19.45	14.27	3.69	1.14	1.13	1.12	2.67	19.20	6.12	7.19
	UIB-Central	0.35	0.21	-0.19	-0.43	9.99	20.49	13.74	20.73	-4.95	-2.15	-0.80	-0.29	-0.30	2.76	17.69	-2.84	3.30
	Western-Karakoram	0.04	0.00	0.00	0.00	0.29	-3.75	-12.69	-13.75	-2.14	-0.24	0.18	0.20	0.13	0.24	-10.23	-0.59	-2.55
	Karakoram	0.28	-0.20	-0.60	0.33	9.67	24.33	8.29	8.13	-7.57	-2.18	-0.59	0.63	-0.15	4.17	24.39	-4.36	6.44
	Hindukush	0.00	0.05	0.04	0.19	3.31	-1.00	-0.85	0.11	0.64	0.23	0.15	0.13	0.04	1.25	0.24	0.31	0.48
	UIB-WU	0.58	0.60	0.33	0.51	3.55	-1.86	-12.74	-12.50	0.68	1.48	1.02	0.71	0.48	1.30	-6.83	1.22	-0.95
	Astore	0.28	0.24	0.32	0.97	3.52	1.29	-0.62	0.54	0.16	0.28	0.32	0.23	0.31	1.63	0.43	0.28	0.76
	Partab_Bridge	1.01	0.49	0.44	1.93	18.03	13.07	12.89	-8.37	9.74	3.84	2.61	1.63	1.74	6.84	7.05	4.93	4.72
	UIB-WL	1.94	1.96	3.49	0.17	2.89	-12.90	-25.95	-12.06	-1.35	1.57	1.94	2.35	1.92	1.93	-13.82	0.48	-2.63
	UIB-WL-Partab	1.58	1.87	2.11	-0.82	-0.30	-22.26	-16.35	-17.07	0.02	-2.20	0.23	1.18	1.32	0.34	-22.10	-0.99	-5.40
	UIB_West	2.02	2.01	2.73	1.12	8.00	-19.88	-32.88	-23.24	-5.13	1.95	2.59	2.40	2.18	3.99	-25.21	0.93	-4.03
	Himalaya	3.23	3.91	4.73	2.33	-0.33	-32.29	-69.33	-17.55	-4.61	-0.05	3.40	2.05	3.37	6.86	-40.09	-0.72	-6.13
	UIB	3.00	3.33	3.53	0.62	12.97	-8.84	-13.31	-3.24	8.19	4.03	3.92	3.04	3.04	5.00	-6.15	5.14	2.23

- Winter discharge features an increasing trend, while for the rest of seasons and on an annual time scale, sites mostly exhibit a mixed response.
- Shift during the seasonal transitional month of June and within the high flow months July-September
  - long term trend: eastern-, central- and whole Karakoram, UIB-Central, Indus at Kachura, Indus at Partab Bridge and Astore regions is increasing while rest of regions is decreasing
  - May attribute to a multi-decadal variability of climatic processes over the region, which is driven by NAO and ENSO



Inter-Annual Trends of UIB sub-basins Discharge

- Astore and Gilgit showing rising discharge trends
- Hunza and Kharmong showing declining discharge trends
- Kachura, Shyok and Shigar showing rising discharge trends
- Overall UIB discharge measured at Besham does not shown any significant trend

Discharge prediction in UIB

Table 5. Percent increase (%) in mean of monthly river flows values of UBC for the period of baseline 1976–2005, and future 2006–2035, 2041–2070, 2071–2100 input from CCAM with RCP4.5 and RCP8.5. *(Ali et al., 2015)*

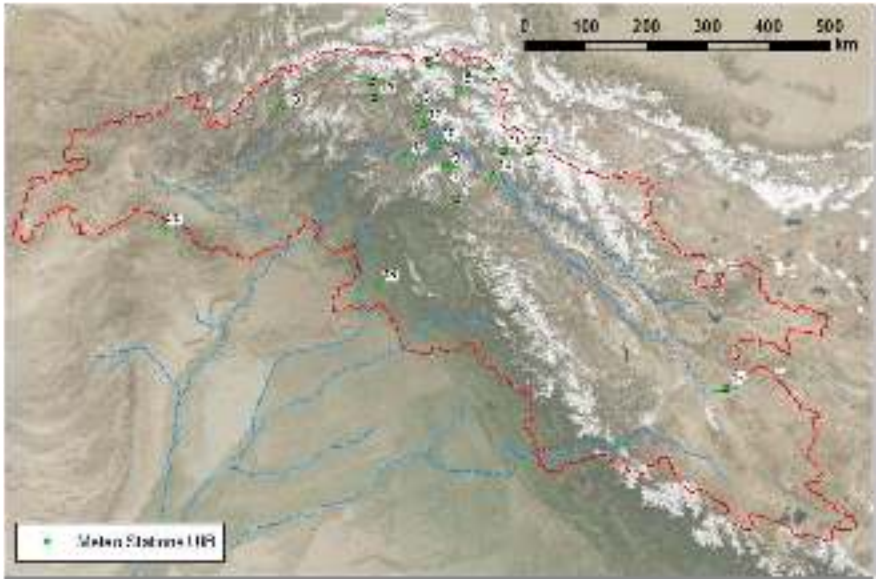
	RCP8.5 (% increase river flow)			RCP4.5 (% increase river flow)		
Month	2006–2035	2041–2070	2071–2100	2006–2035	2041–2070	2071–2100
October	73	111	144	59	85	73
November	85	110	157	85	112	85
December	75	75	81	64	119	55
January	93	68	118	78	101	37
February	122	138	242	106	164	110
March	253	253	576	218	271	178
April	104	142	322	114	115	112
May	60	119	215	58	95	63
June	30	78	82	37	44	36
July	21	41	39	21	28	24
August	20	37	50	16	28	21
September	27	52	73	21	37	22
Average	34	63	87	33	46	35

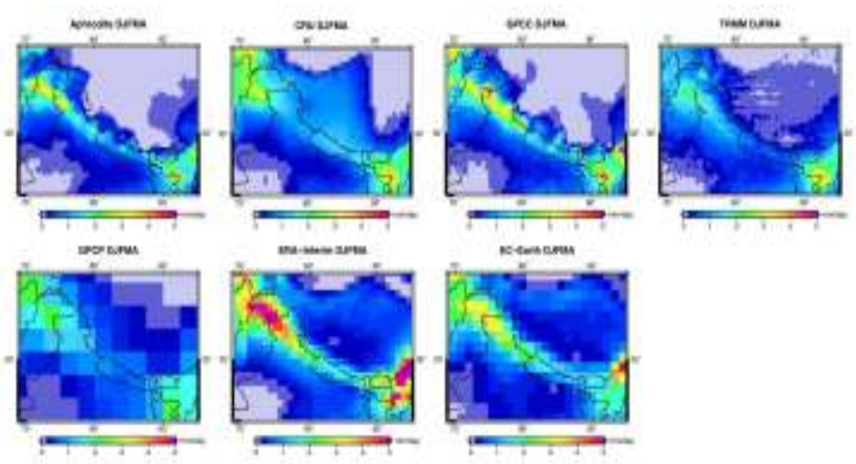
- Future river flow is projected by both models (CCAM and RegCM) to increase in the twenty first century in both scenarios.
- The percentage of increased river flow is larger in winter than in summer

ICIMOD-FutureWater-PMD-WAPDA

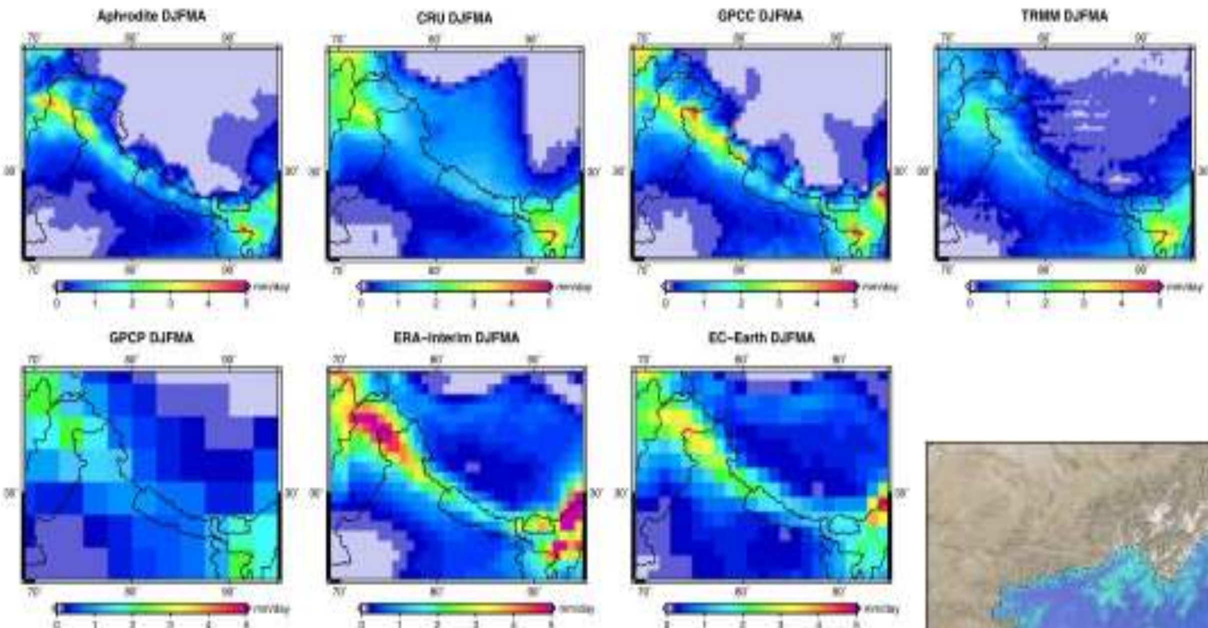
Gridded Meteorological Datasets and Hydrological Modelling in the Upper Indus Basin

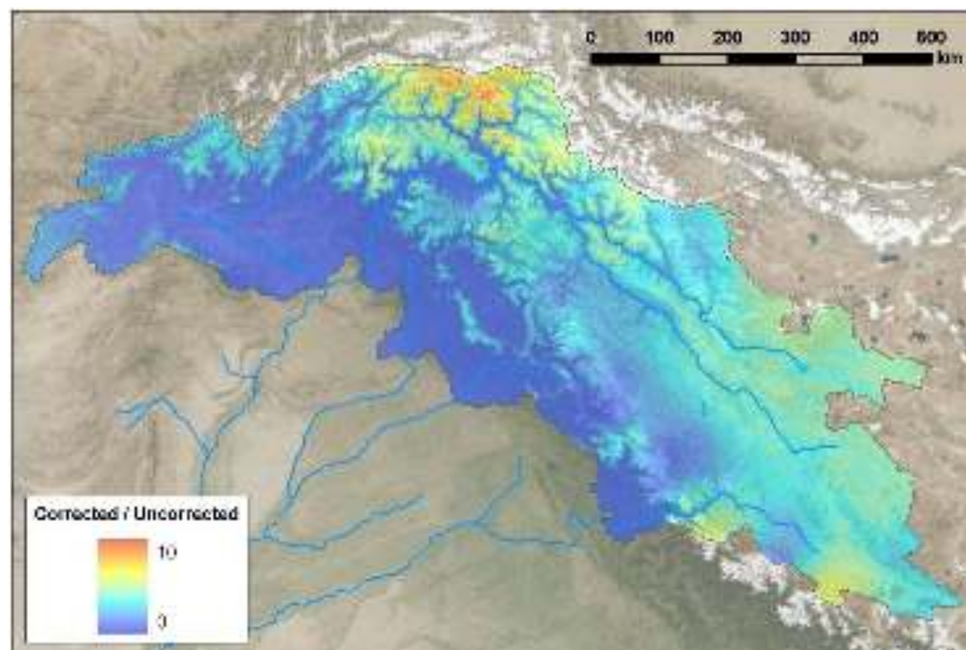
- To develop a high-quality meteorological forcing dataset (temperature and precipitation) for the UIB by merging existing gridded datasets and high-altitude climate observations.
- To improve the existing large-scale SPHY model and recalibrating the model with additional observations (geodetic mass balance, time series of river runoff, time series of reservoir inflow data).
- Test a new approach for statistical downscaling
- To use the recalibrated SPHY model to examine shifts in the basin hydrology under CMIP5 climate change scenarios.





Improve historical climate datasets





Ongoing work/future plan

- Improve hydromet monitoring of Simshal valley (ICIMOD/PARC/PMD); Equipment procurement in process.
- Improvement of SPHY model
- Second SPHY training in December