

Supplement for

Climate Change Reshaping the Water Cycle in Arid Central Asia

Table S1. Summary of observational data on glacier mass balance in the Tianshan Mountains.

Range	Subregion	Period	Mass balance (m w.e. a ⁻¹)	Method	Scale	Reference
Northern Tianshan	Total Northern Tien Shan	1964–2020	-0.40 ± 0.09	Geodetic	Regional	[1]
	Molodezhniy		-0.39 ± 0.04		Glacier	
	Igly Tuyuksu		-0.37 ± 0.04		Glacier	
	Kosmodemjanskaya		-0.30 ± 0.04		Glacier	
	Ordzhonikidze	1958–2016	-0.25 ± 0.04	Geodetic	Glacier	
	Mayakovskiy		-0.29 ± 0.04		Glacier	[2]
	Mametova		-0.36 ± 0.04		Glacier	
	Glacier No.1		-0.42 ± 0.04		Glacier	
	Glacier No.2	1958 - 1998	-0.48 ± 0.06		Glacier	
	Total Tuyuksu	1958–2016	-0.35 ± 0.04	Geodetic	Regional	
	Manas River Basin	2000–2016	-0.58	Model-based	Basin	[3]
Central Tien Shan	Qingbingtian Glacier No. 72	2008–2014	$+0.86 \pm 0.19$	Glaciological	Glacier	[4]
	Golubin Glacier	1972–2016	-0.30 ± 0.40	Model-based	Glacier	[5]
	Total Central Tien Shan	1975–1999	-0.35 ± 0.34	Geodetic	Regional	[6]
		1999/00– 2017/18	-0.13 ± 0.37	Geodetic/hybrid	Regional	[7]
	Karabatkak	1973–1999	-0.54 ± 0.25	Glaciological	Glacier	[6]
		2000–2018	-0.19	Geodetic		[8]
	Ak-Shirak	1964–2019	-0.40 ± 0.07	Geodetic	Regional	[1]
	Aksu/Sary-Djaz	1975–1999	-0.35 ± 0.34	Geodetic	Regional	[6]
	Inylchek	1975–1999	-0.20 ± 0.44	Geodetic	Regional	
	Aksu River Basin	1957–2017	-0.0946	Model-based	Basin	[9]
	Southern Inylchek	1975–2007	-0.42 ± 0.11	Geodetic	Glacier	[10]
	Northern Inylchek	1959–2008	-0.43 ± 0.03	Geodetic	Glacier	
	Keqikar	2003–2005	-0.44	Glaciological	Glacier	[11]
	Tomur		-0.33 ± 0.30	Geodetic	Regional	
	Petrov		-0.59 ± 0.25	Geodetic	Glacier	
	Dschamansu		-0.68 ± 0.38	Geodetic	Glacier	
	Sauntor		-0.44 ± 0.37	Geodetic	Glacier	
	Bulantor		$+0.22 \pm 0.42$	Geodetic	Glacier	
	Kaindy	1975–1999	-0.27 ± 0.42	Geodetic	Glacier	[6]
	Samoilowitsch		-0.09 ± 0.42	Geodetic	Glacier	
	Koxkar		-0.34 ± 0.26	Geodetic	Glacier	
	Kiqikterang		-0.48 ± 0.30	Geodetic	Glacier	
	Keqikekuzibayi		$+0.02 \pm 0.22$	Geodetic	Glacier	
	Bordu- Juschnaja		-0.79 ± 0.25	Geodetic	Glacier	
		2000–2018	-0.35	Geodetic		[8]
Western Tien Shan	Sary-Tor	1973–1999	-0.51 ± 0.25	Glaciological	Glacier	[6]
		2000–2018	-0.43	Geodetic		[8]
	Batysh	2003/04– 2015/16	-0.39 ± 0.26	Model-based	Glacier	[12]
	Gregoriev	2006–2007	-0.36	Geodetic	Glacier	[13]
	West Tien Shan	2000–2021	-0.15 ± 0.10	Geodetic	Regional	[14]
	Glacier No. 354	1975–1999	-0.79 ± 0.25	Geodetic	Glacier	[6]
		2003–2014	-0.43 ± 0.09	Model-based		[15]
	Barkrak	2000–2012	-0.82 ± 0.36	Geodetic	Glacier	[16]
		2023	-0.628	Geodetic		
	Pskem River	2012–2014	-1.08	Geodetic	Regional	
Eastern Tien Shan	Tekesh	2012–2014	-0.136	Geodetic	Glacier	
	East Tien Shan	2000–2021	-0.47 ± 0.07	Geodetic	Regional	[14]

Range	Subregion	Period	Mass balance (m w.e. a ⁻¹)	Method	Scale	Reference
Eastern Tien Shan	Karlik	1972–2016	-0.18 ± 0.02	Model-based	Regional	[17]
	Haxilegen Glacier No.51	1964–2018	-0.36 ± 0.12	Geodetic	Glacier	[18]
Total Tien Shan		1961–2020	-0.36	Model-based	Regional	[19]

Table S2. Summary of observational data on glacier mass balance in the Pamir region.

Range	Subregion	Period	Mass balance (m w.e. a ⁻¹)	Method	Scale	Reference
Central Pamir	Fedchenko	1975-1999	-0.09 ± 0.28	Geodetic	Glacier	[20]
		2000–2016	-0.35 ± 0.07	Geodetic	Glacier	[21]
	Ulugbeka		+0.05 ± 0.22			
	Yazgulem		+0.17 ± 0.30			
	Abdukgor		+0.07 ± 0.24			
	Tanimas-2		+0.01 ± 0.32			
	Tanimas-3		-0.12 ± 0.26			
	Grum		+0.03 ± 0.32			
	RGS		+0.09 ± 0.22			
	Little Tanimas		-0.02 ± 0.32			
	Ayujilga	1975-1999	+0.08 ± 0.22	Geodetic	Glacier	[20]
	Mushketov		+0.06 ± 0.26			
	N. Kyskurgan		-0.12 ± 0.26			
	Kosinenko		-0.08 ± 0.26			
	Bears		+0.09 ± 0.30			
	Bivachny		-0.05 ± 0.33			
	Vavilov		+0.26 ± 0.22			
	Shokalski		+0.08 ± 0.22			
	N. Tanimas		-0.01 ± 0.19			
	Ravak		+0.63 ± 0.20			
Eastern Pamir	Muztag Ata	1967–2019	-0.06 ± 0.07	Geodetic	Glacier	[1]
	Muztag Ata No.15 Glacier	1980–2012	-0.063	Model-based	Glacier	[22]
	Kongur Tagh		+0.17 ± 0.04	Geodetic	Glacier	
	Kingata (n-s combined)	2000–2015/16	-0.04 ± 0.04	Geodetic	Regional	[23]
	Kingata (north)		-0.07 ± 0.04	Geodetic	Regional	
	Kingata (south)		+0.02 ± 0.03	Geodetic	Regional	
	Total Eastern Pamir	1999/00– 2017/18	-0.12 ± 0.37	Model-based	Regional	[7]
Western Pamir	Total Western Pamir	1999/00– 2017/18	-0.25 ± 0.37	Model-based	Regional	[7]
Pamir		2000-2021	-0.07 ± 0.12	Geodetic	Regional	[14]

Table S3. Observed glacier mass-balance changes in mountain ranges relevant to arid Central Asia.

Range	Subregion	Period	Mass balance (m w.e. a ⁻¹)	Method	Scale	Reference
Pamir-Alay	Abramov Glacier	1968–2014	-0.44 ± 0.10	Geodetic/Model- based	Glacier	[24]
	Total Pamir- Alay	1999/00–2017/18	-0.32 ± 0.37	Model-based	Regional	[7]
Karakoram	Total	1973–2000	-0.09 ± 0.03	Geodetic	Regional	[25]
	Karakoram	2000–2023	-0.04 ± 0.09	Geodetic	Regional	[26]
	Shimshal Glacier	2011–2013	+0.31 ± 0.06	Model-based	Basin	[27]
	Central Karakoram	1974–2000	-0.04 ± 0.05	Geodetic	Regional	[25]
	Eastern Karakoram	1974–2000	-0.07 ± 0.05	Geodetic	Regional	[25]

Range	Subregion	Period	Mass balance (m w.e. a ⁻¹)	Method	Scale	Reference
	Western Karakoram	1973/74–2000	-0.11 ± 0.04	Geodetic	Regional	[25]
	Batura	1996–2020	-0.236 ± 0.014	Remote sensing-derived MB	Glacier	[28]
	Hispar	1996–2020	-0.20 ± 0.023	Remote sensing-derived MB	Glacier	[28]
	Siachen Glacier	1999–2007	-0.03 ± 0.21	Geodetic	Glacier	[29]
Altai, China	Total Altai, China	1959–2008	-0.43 ± 0.03	Geodetic	Regional	[30]
	Sawir Mountains	1959–2021	-0.47 ± 0.11	Geodetic	Regional	[31]
Kunlun	Total Kunlun	2000–2016	$+0.14 \pm 0.08$	Geodetic	Regional	[32]
	East Kun Lun	2000–2021	-0.09 ± 0.07	Geodetic	Regional	[14]
	West Kun Lun	2000–2021	$+0.23 \pm 0.13$	Geodetic	Regional	[14]
Dzhungarsky Alatau		1999/00–2017/18	-0.46 ± 0.37	Model-based	Regional	[7]

Table S4. Major reference glaciers with annual in situ surface mass-balance observations in Central Asia.

Glacier	Country	Mountain region	Observation period	Recent/representative SMB (m w.e. a ⁻¹)	Reference
Urumqi Glacier No. 1	China	Eastern Tien Shan	1959–2025	–1.815 (2023/24)	[33,34]
Kangxiwa Glacier	China	Eastern Pamir	since 2010/11; observations through 2025	—	[33]
Central Tuyuksu	Kazakhstan	Northern Tien Shan	1956–2025 (continuous)	–0.761 (2023/24)	[33,34]
Golubin	Kyrgyzstan	Northern Tien Shan	from 1968; re-established in 2010; observations through 2025	–1.900 (2023/24)	[33–35]
Abramov	Kyrgyzstan	Pamir-Alay	1968–1994; seasonal observations to 1998; re-established in 2011	–0.672 (2023/24)	[33–35]
Glacier No. 599	Kyrgyzstan	Northern Tien Shan	2014–2025	–1.144 (2023/24)	[33,34]
Batysh-Sook	Kyrgyzstan	Central Tien Shan	1970/71, 1983/84, 1988–1991; re-established in 2010	–1.491 (2023/24)	[33–35]
Glacier No. 354	Kyrgyzstan	Inner Tien Shan	2010–2025	–2.138 (2023/24)	[33–35]
Bordu	Kyrgyzstan	Inner Tien Shan	2015–2025	–1.220 (2023/24)	[33,34]
Sary-Tor	Kyrgyzstan	Inner Tien Shan	1985–1989; re-established in 2013/14	–1.090 (2023/24)	[33–35]
Kara-Batkak	Kyrgyzstan	Inner Tien Shan	since 1956, with historical gaps; observations through 2025	–0.810 (2023/24)	[33–35]
Turgen-Aksuu	Kyrgyzstan	Central Tien Shan	2018–2025	–1.080 (2023/24)	[33,34]
Barkrak Sredniy	Uzbekistan	Western Tien Shan	re-established in 2016; 9 annual observations through 2025	—	[33,35]
Sangvor	Tajikistan	Western Pamir	3 annual observations through 2025	—	[33]
East Zulmart (No. 139)	Tajikistan	Pamir	2019/20–2022/23 published; 7 annual observations through 2025	–0.271 (2023/24)	[33,34]

Glacier No. 457	Tajikistan	Western Pamir	5 annual observations through 2025	−0.468 (2023/24)	[33,34]
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Table S5. Runoff-component contributions for the 31 river catchments shown in Figure 5.

No. in Fig. 5	River / catchment	Glacier melt (%)	Snowmelt (%)	Rainfall (%)	Groundwater (%)	Reference
1	Amu	39.7	43.1	17.2	NR	[36]
2	Zeravshan	57.7	25.8	16.5	NR	
3	Wakhsh	59.3	22.4	6.5	11.8	
4	Pyanj	26.2	NR	NR	NR	[37]
5	Muzat	67.5	12.6	14.8	5.1	[38]
6	Chakmak	34	NR	36	30	[39]
7	Yarkand	53	NR	26.4	20.6	[40]
8	Aksu	31	5	10	54	[41]
9	Hotan	52.5	NR	35.75	11.75	[40]
10	Cele	30	NR	40	30	[39]
11	Kaishi	14.1	11.5	25.4	49	[38]
12	Keriya	24	NR	52	24	[39]
13	Niya	23	NR	55	22	[39]
14	Bostan Toghrak	29	NR	39	32	[39]
15	Tarim	41.5	NR	NR	NR	[42]
16	Cherchen	35	NR	25	40	[39]
17	Alagou	14	26.8	29.8	29.4	[38]
18	Urumqi	10.1	13.8	42.2	33.7	[38]
19	Hutubi	12.5	14.5	38.6	34.4	[38]
20	Manasi	30.6	16.6	33.4	19.4	[38]
21	Kaidu	8.2	25.1	21.1	45.6	[38]
22	Baiyang	32.7	16.7	34.3	16.3	[38]
23	Irtys	1	NR	71	28	[40]
24	China-Ili	18.5	NR	NR	NR	[43]
25	Jinghe	13.8	13.4	30.6	42.2	[38]
26	Kuche	7.3	14.4	51.2	27.1	[38]
27	Kalasu	29.6	18	33.3	19.1	[38]
28	Weigan	31	NR	14	55	[39]
29	Tailan	61	14.3	18.9	5.8	[38]
30	Inner Tien-Shan	19	58	23	NR	[44]
31	Naryn	7	68	25	NR	[45]

Note: Values are percentages of total runoff as reported in the cited source studies. Glacier melt and snowmelt are listed separately only where the original study reported them as independent components. NR indicates that a component was not independently reported and should not be interpreted as a zero contribution. Because the source studies use different runoff-partitioning methods and component definitions, the values are retained as reported and no missing component was inferred or re-normalized.

Table S6. Rates of runoff change across major river basins in arid Central Asia.

Region	River	Station	Period	Runoff change rate (mm/a)	Reference
Ob - Irtysh BS	Ishim	Petropavlovsk	1933–2016	-0.13	[46]
	Zhabay	Atbasar	1955–2014	0.26	[47]
	Tobol	Grishenka	1955–2014	-0.02	[48]
	Tobol	Kostanay	1934–2017	-0.14	
	Irtysh	Ust-Kamenogorsk	1963–2019	1.23	[49]
	Oba	Shemonaikha	1975–2015	-1.86	
	Burqin	Qunkule	1957–2008	2.03	[50]
Junggar Interior BS	Yiwu	Weizixia	1977–2007	0.87	[50]
	Hutubi	Headwork	1979–2005	0.71	[51]
	Baiyang	730	1962–2007	0.50	[52]
	Manas	Kensiwate	1959–2010	1.21	[53]
		Hongshanzui	1957–2006	0.83	[54]
	Kuitun	Jiangjunmiao	1964–2010	0.74	[55]
	Urumqi	Yingxiongqiao	1959–2007	0.64	[46]
	Jinghe	Jingheshankou	1961–2008	6.12	[50]
	Qingshui	Kerguti	1956–2012	0.98	[56]
	Kaidu	Dashankou	1960–2012	0.91	[57]
Tarim BS	Kamuslang	Kamuluke	1956–2006	2.67	[50]
	Kalasu	Kalasu	1956–2006	2.24	
	Toxkan	Shaliguilanke	1979–2015	0.95	[58]
	Kumalak	Xiehela	1979–2015	0.44	
	Yarkant	Kaqun	1957–2008	0.34	[59]
	Kashgar	Wuluwati	1957–2008	0.06	[50]
	Kushan	Shaman	1956–2018	0.40	[60]
	Keriya	Numaitilangan	1957–2009	0.34	[50]
	Tiznap	Yuzimenleke	1958–2008	0.72	[61]
	Cherchen	Qiemu	1957–2021	0.16	[62]
	Tarim	Alar	1957–2006	0.12	[63]
	Tarim	Yingbaza	1957–2006	-0.76	
	Tarim	Qiala	1957–2006	-0.52	
	Ili	Ushjarma	1950–2014	0.00	[64]
	Ili	Kapchagay	1950–2014	0.07	
	Ili	Dobyn	1950–2014	0.96	
	Ili	Yamate	1950–2014	0.50	
	Tekes	Tekes	1950–2014	0.33	
Ili–Balkhash BS	Kunes	Kunes	1950–2014	1.13	[64]
	Kashi	Kashi	1950–2014	1.69	
	Karatal	Tekeli	1950–2014	1.31	
	Ayaguz	Ushtobe	1950–2014	0.02	[64]
		Ayaguz	1950–2014	-0.08	
	Lepsy	Lepsinsk	1950–2014	2.37	[65]
	Zeravshan	Pinen	1957–2007	0.06	
	Surkhab	Karatog	1957–2007	-0.36	
	Kafirnigan	Alibegi	1957–2007	-5.02	
	Kofarnihon	Khazarnova	1957–2007	1.78	
Amu BS	Amu Darya	Kelif	1950–2019	0.33	[66]
		Kerki		-1.28	
		Tuyamuyun		-2.28	
		Kiziljar		-2.13	
	Vakhsh	Garm	1960–2010	6.18	[67]
		Dombrachi	1955–2022	5.51	[68]
Syr BS and around	Gunt	Khorog	1960–2015	-0.88	[65]
	Sarysu	Kyzylzhar	1955–2014	-0.0004	
	Syr Darya	Karateren	1960–2020	-0.01	[69]
		Uchkurgan	1960–2014	0.78	
	Naryn	Naryn town	1932–2020	6.97	[68]
	KaraDarya	Andijan	1950–2021	4.04	

Region	River	Station	Period	Runoff change rate (mm/a)	Reference
	Chu	Chapaev	1936–2015	-0.19	[68]
	Talas	Ak-Tash	1957–2009	3.65	[70]

Note: Streamflow data for the Gunt station at Khorog for the period 1960–2015 were provided by the Agency for Hydrometeorology of the Committee for Environmental Protection under the Government of the Republic of Tajikistan.

Table S7. Projected runoff changes in Central Asia under different climate scenarios.

Basin / sub-basin	Projected runoff changes	Method
Ili River Basin	Relative to 1960–2020, annual runoff is projected to increase by 12.8% under SSP2-4.5 and 14.3% under SSP5-8.5 during 2021–2100. Historical attribution analysis for 1960–2020 indicates that climate change contributed 104.59%–113.07% to streamflow variation, whereas land-use change contributed –10.75% to –4.59% and reservoir construction contributed –2.27%. Under future climate scenarios, the proportion of surface runoff increases while that of groundwater flow decreases. Reservoir regulation was not included in the future streamflow projections.	Hybrid hydrological prediction model; considers the effects of climate change, land-use change, and reservoir construction [71].
Syr Darya Basin	Relative to 1979–2011, runoff changes by +2%, +3%, +6%, and +3% under SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5 during 2011–2040, respectively; by +6%, +1%, -1%, and +2% during 2041–2070; and by +1%, 0%, +1%, and -6% during 2071–2100. Overall, annual runoff changes are relatively small, but a runoff decline emerges in the far future under the high-emission scenario.	Stochastic soil-moisture water-balance model [72].
Upper Syr Darya Basin - above Chardara	By the end of the 21st century, summer runoff decreases by 16%–30% under RCP4.5/RCP8.5, while peak flood discharge increases by >60%.	VIC-glacier model driven by downscaled and bias-corrected multi-GCM climate data [73].
Upper Syr Darya Basin (>2000 m a.s.l.)	Relative to 1985–2014, annual runoff during 2071–2100 shows small changes to increases under wet scenarios: $+0.1 \pm 16.6\%$ under warm-wet and $+15.0 \pm 17.6\%$ under cold-wet. In contrast, runoff decreases markedly under dry scenarios: $-49.0 \pm 12.6\%$ under warm-dry and $-37.8 \pm 14.0\%$ under cold-dry.	SPHY cryosphere-hydrology model driven by CMIP6-based climate scenarios [74].
Syr Darya Basin - Naryn River	During the 21st century, multi-year mean runoff is projected to range from 410.6 to 649.8 m ³ /s. In the 2080s, peak flow increases by 36.6%, while low flow decreases by 36.8%.	MSEP multi-scenario ensemble prediction framework coupling GCMs, CA-Markov land-use simulation, and SWAT [75].
Syr Darya Basin - Naryn River	Relative to 1976–2005, annual runoff during 2016–2045 decreases by approximately 4.01%–9.22% under A1B, RCP2.6, RCP4.5, and RCP8.5. Under the high-emission scenario, runoff decreases by 16.88% during 2066–2095. Glacier melt peaks around 2040 and then declines with glacier retreat; the runoff peak advances by about one month.	SWAT-G model considering climate scenarios and glacier changes [76].
Glacierized Upper Syr Darya Basin	Relative to 2000–2020, glacierized-basin runoff first increases by 15%–24% and peaks before 2050, then decreases by 14%–20% by 2100. Glacier volume is projected to decline by 69%–93% by 2100.	Global/regional glacier-model and water-availability assessment framework [33].
Amu Darya Basin	Relative to 1953–2019, annual runoff is projected to increase by 17.1% to 18.6%, 14.7% to 25.0%, and 11.7% to 29.3% during 2020–2049, 2050–2079, and 2080–2100, respectively. The increase weakens in the far future under the low-emission scenario, whereas relatively large increases persist under SSP3-7.0 and SSP5-8.5. By 2080–2100, rainfall runoff increases by 57.9% to 106.5%, while snowmelt runoff changes by +0.1% to -	VIC-glacier model driven by CMIP6 scenarios [77].

Basin / sub-basin	Projected runoff changes	Method
	9.1%. Seasonally, the snowmelt peak shifts from June to April, and the sharp August glacier-melt peak weakens and spreads to adjacent months.	
Upper Amu Darya Basin - above Kerki station	Relative to 1971-2000, annual runoff under RCP8.5 increases by $9 \pm 12\%$ in 2020-2049 and $15 \pm 22\%$ in 2070-2099. By the end of the century, rainfall runoff contributes 55% to 69% of the total runoff increase, indicating a gradual shift from snow- and glacier-melt dominance toward stronger rainfall contribution.	VIC-glacier model driven by downscaled and bias-corrected multi-GCM climate data [73].
Upper Amu Darya Basin, mountainous catchment	Relative to 1985-2014, annual runoff in 2071-2100 increases under wet scenarios: $+19.6 \pm 14.4\%$ under warm-wet and $+24.3 \pm 14.6\%$ under cold-wet. In contrast, runoff decreases under dry scenarios: $-27.2 \pm 12.9\%$ under warm-dry and $-23.4 \pm 13.2\%$ under cold-dry. The runoff peak shifts from June to April to May.	SPHY cryosphere-hydrology model driven by CMIP6-based climate scenarios [74].
Amu Darya Basin - Vanj River	Relative to 2000-2023, annual runoff in 2077-2100 decreases by 33.0%, 32.7%, and 17.3% under SSP1-2.6, SSP2-4.5, and SSP5-8.5, respectively; glacier melt decreases by 77.2%, 67.1%, and 48.1%. Mean discharge declines from 41.5 m ³ /s in the historical period to 27.8, 27.9, and 34.3 m ³ /s in the far future. Under SSP5-8.5, the runoff peak shifts to June, and the snowmelt peak advances by about one month; under SSP1-2.6 and SSP2-4.5, it advances by about half a month.	SPHY model driven by ERA5 and CMIP6 multi-GCM data after downscaling and bias correction [78].
Amu Darya Basin - Vakhsh River	Relative to 1966-2004, annual runoff in 2022-2060 changes by -6.4% to +7.4% under RCP4.5, with an ensemble mean of -1.25%, and by -3.3% to +7.8% under RCP8.5, with an ensemble mean of +0.73%. In 2061-2099, runoff changes by -2.7% to +25.6% under RCP4.5, with an ensemble mean of +6.90%, and by +17.5% to +52.3% under RCP8.5, with an ensemble mean of +28.73%. The runoff peak shifts from July to June, and spring runoff increases by 30.59% to 95.69%.	SWAT model driven by five CMIP5 GCMs [79].
Amu Darya Basin - Zeravshan, Kafirnigan, and Tupalang rivers	Relative to the historical period, future runoff under RCP4.5/RCP8.5 shows a clear seasonal redistribution, with increased spring runoff but decreased summer and early-autumn runoff. Summer runoff in the Zeravshan River decreases by up to approximately 60%. The Kafirnigan and Tupalang rivers also show spring increases and summer to autumn decreases. Runoff peaks advance by up to one month, and runoff during June to September decreases in most basins.	SWIM ecohydrological model with snow processes and a simplified glacier module, driven by five bias-corrected GCMs [80].
Tarim River Basin - Kaidu River	Fang et al. reported that, relative to 1976-2005, runoff in the Kaidu River generally decreases by approximately 3%-8% under RCP4.5/RCP8.5 during 2006-2095. Gao et al. also found a decreasing trend: relative to 1981-2015, runoff during 2036-2065 decreases by approximately 9.1% and 12.1% under RCP4.5 and RCP8.5, respectively. In contrast, Lyu et al. projected increases of 11% and 18% by the end of the 21st century under SSP2-4.5 and SSP5-8.5, respectively, relative to 2000-2014.	SWAT-Glacier model driven by six CORDEX RCMs [81] Multi-model ensemble including SWAT-Glacier, H08, and GloGEM [82]
Tarim River Basin - Aksu River	Fang et al. showed that runoff in the Aksu River generally increases during 2006-2035, 2036-2065, and 2066-2095. Lyu et al. also projected increasing runoff: relative to 2000-2014, runoff increases by 10% and 21% by the end of the 21st century under SSP2-4.5 and SSP5-8.5, respectively. However, Wortmann et al. suggested that, relative to 1971-2000, runoff first increases by about 20% but returns to the baseline level or declines by 2071-2100, indicating a weakening runoff gain after glacier retreat.	Attention-based multifactor LSTM model coupled with CMIP6 scenarios and glacier runoff datasets [83] SWIM-G and WASA glacier-hydrological models driven by eight GCMs under three emission scenarios [84]
Tarim River Basin - Yarkand River	Xiang et al. projected that, relative to 1986-2014, runoff in the Yarkand River increases by 10.62%-19.2% during 2021-2049 and by 36.69%-70.4% during 2071-2099, with the runoff peak shifting from August to July. Wortmann et al. also projected increases of approximately 15%, 30%, and 60% by 2071-2100 under low-, medium-, and high-emission scenarios, respectively, relative to 1971-2000. Fang et al. also showed a marked increase in summer runoff. In contrast, Liu et al. projected that, relative to	Modified HEC-HMS distributed hydrological model driven by CMIP6 SSP scenarios [85,86] Liu: improved SPHY model driven by bias-corrected

Basin / sub-basin	Projected runoff changes	Method
	2000-2014, runoff during 2081-2100 reaches only 50.4%, 60.4%, 81.3%, and 95.6% of the baseline level under SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, respectively, with summer runoff decline mainly caused by reduced glacier melt.	outputs from five CMIP6 GCMs [87]
Tarim River Basin - Hotan River	Gao et al. projected that, relative to 1976-2005, runoff in the Hotan River continues to increase by approximately 6.25%-15.2% during 2036-2065. Fang et al. showed a marked increase in summer runoff. Wortmann et al. projected that, relative to 1971-2000, runoff increases by approximately 15%, 30%, and 60% by 2071-2100 under low-, medium-, and high-emission scenarios, respectively. Lyu et al. further indicated that the Hotan River is one of the headwater rivers with the most pronounced runoff increase by the end of the 21st century.	
Tarim River Basin - Karakash River	Liu et al. projected that, relative to 2000-2014, runoff in the Karakash River during 2081-2100 reaches only 47.8%, 50.0%, 57.6%, and 59.5% of the baseline level under SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, respectively. Glacier melt decreases rapidly after 2030, and the projected summer runoff decline is mainly caused by reduced glacier melt.	
Tarim River Basin - Yulongkashi River	Liu et al. projected that, relative to 2000-2014, runoff in the Yulongkashi River during 2081-2100 reaches only 47.8%, 60.1%, 78.9%, and 84.9% of the baseline level under SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, respectively. The contribution of glacier melt continues to decline, and the dominant runoff component gradually shifts from glacier melt to rainfall/snowmelt. However, Lyu et al. indicated that runoff after glacier peak water does not necessarily fall immediately below the historical level.	
Tarim River Basin - Huangshuigou River	Relative to the baseline period, runoff increases by approximately 3.8% and 3.6% during 2020-2039 under RCP4.5 and RCP8.5, respectively, but changes by approximately -0.3% and -8.5% during 2080-2099. Monthly runoff generally decreases, with the largest decline occurring in summer.	SWAT model driven by GCM climate scenarios [88]

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