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SUPPLEMENTARY INFORMATION

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# Agricultural risks from changing snowmelt

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**Supplementary Figures and Tables for**

**Agricultural risks from changing snowmelt**

**Yue Qin et al.**

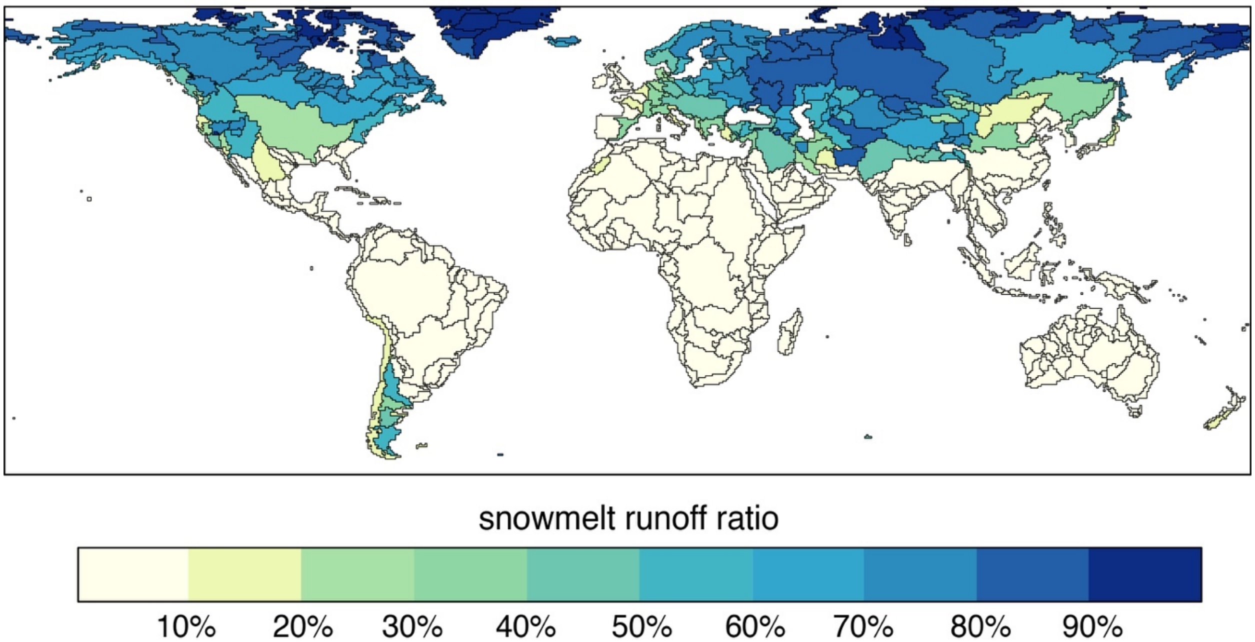


**Figure S1 | Geographical pattern of snowmelt runoff during recent decades (1985–2015) by basin.** Share of annual average total runoff from snowmelt (Fig. 1) aggregated to basins.

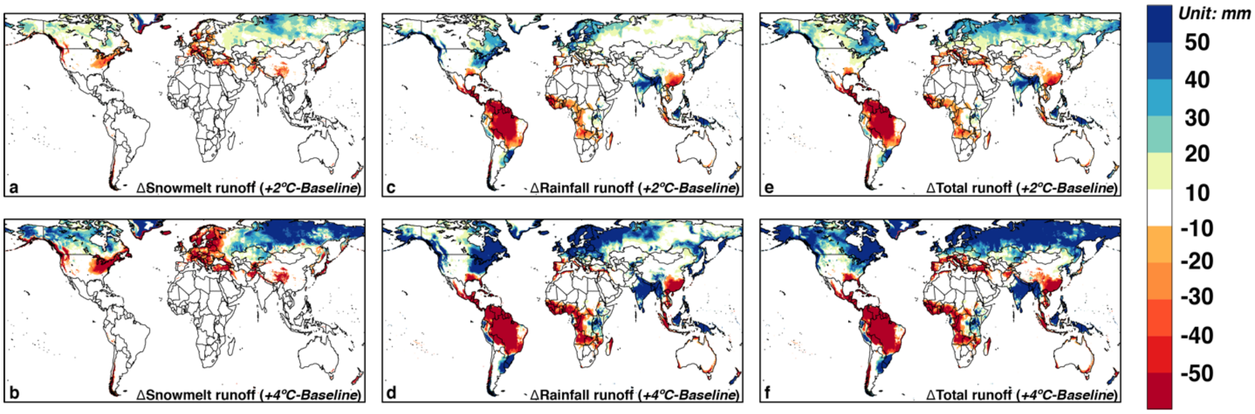


**Figure S2 | Grid-level changes in annual average snowmelt runoff, rainfall runoff, and total runoff under the 2°C and 4°C warming scenarios in comparison to the 1985–2015 baseline.** We observe, particularly under the 4°C warming scenario, notable snowmelt runoff decreases in Western Europe, western China, northeastern and western U.S., southern Andes, and et al, while increases in Russia, Canada, and Alaska. Rainfall runoff and net runoff show a much different pattern than snowmelt runoff. For instance, notable rainfall runoff increases occur in eastern and western North America, India, and northern Europe, while decreases in northern parts of South America, western Africa, and southeastern China. Similarly, net runoff increases in eastern and western U.S., northern Europe, and Russia, while decreases in northern parts of South America, western Africa, and southeastern China.

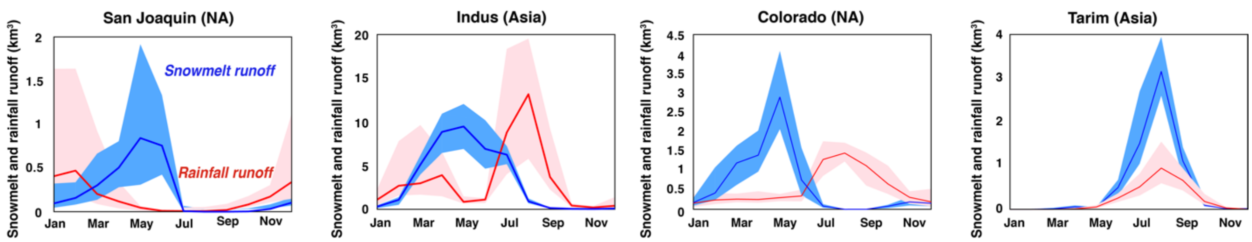


**Figure S3 | Monthly snowmelt runoff and rainfall runoff in selected basins corresponding to Figure 2 for the period of 1985–2015.** Solid lines are 1985–2015 median value; shaded areas represent monthly 25th and 75th percentiles for snowmelt runoff (blue) and rainfall runoff (red), respectively.

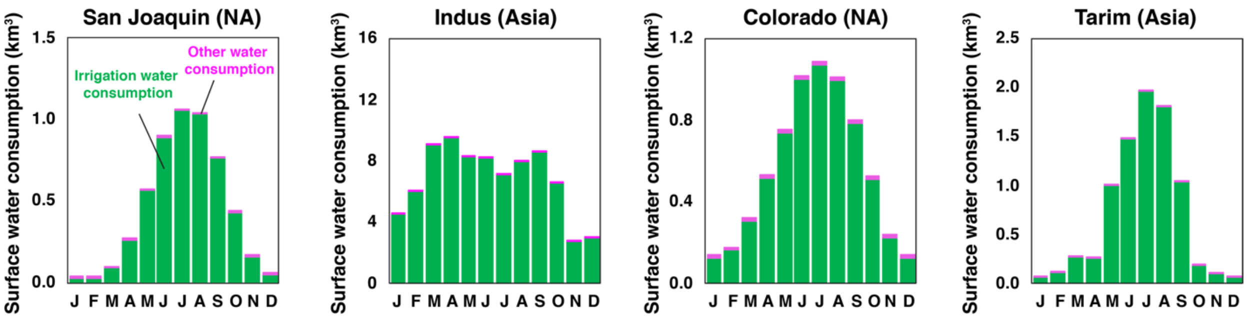


**Figure S4 | Monthly average surface water demand for the period of 1985–2015 for irrigation and other purposes in selected basins corresponding to Figure 2.**

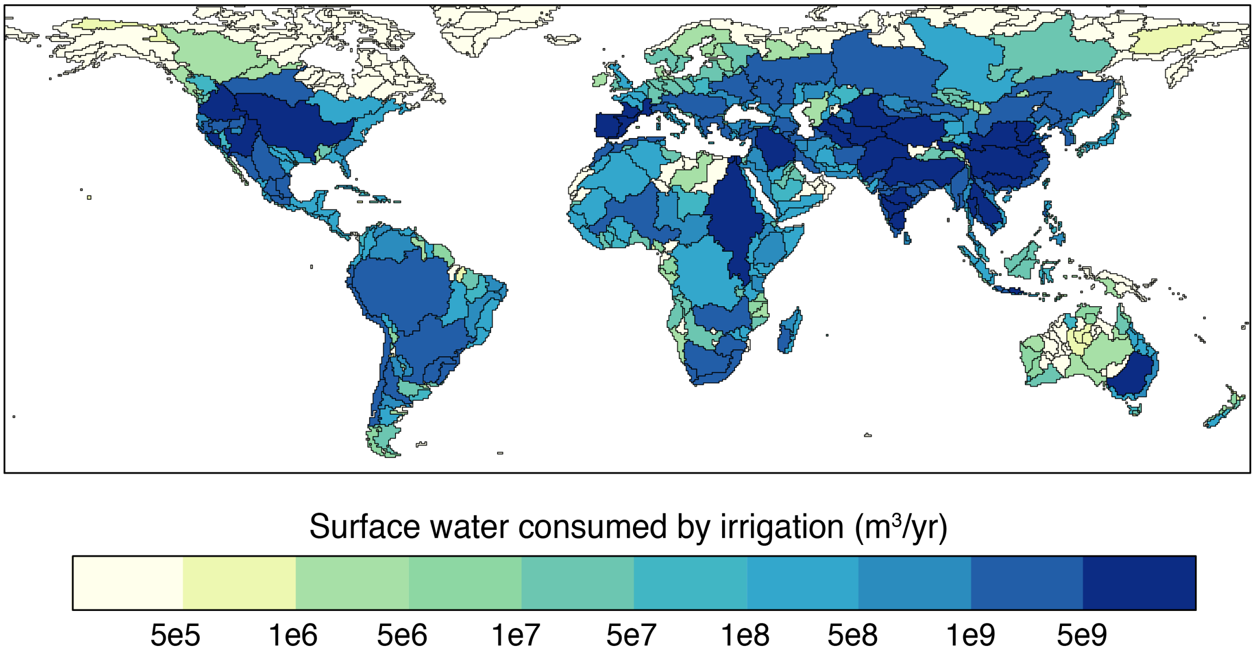


**Figure S5 | 1985-2015 basin-level annual average irrigation surface water consumption.**

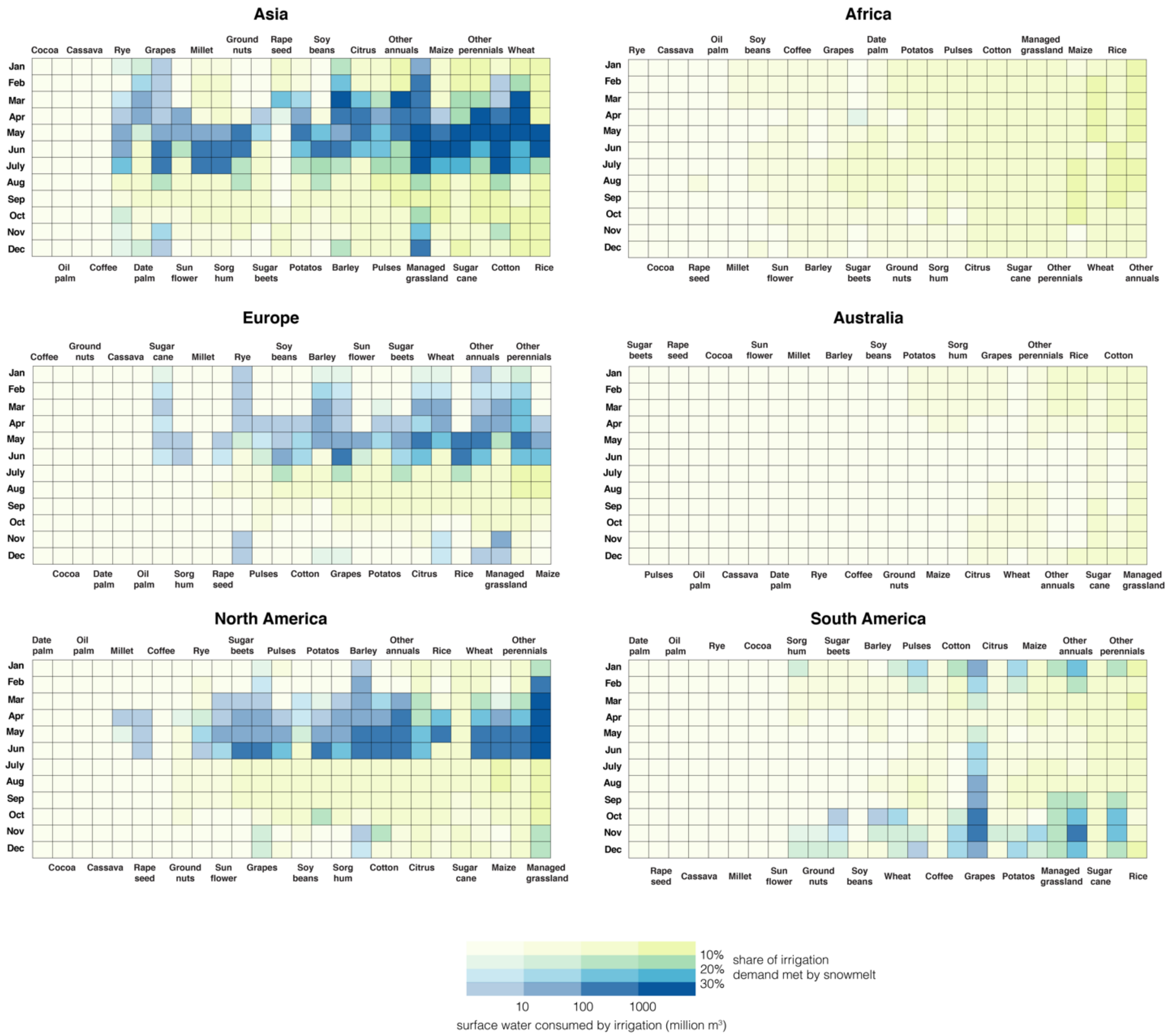


**Figure S6 | Regional snow dependence by crop type** (1985–2015)**.** Colors indicate the average share of irrigation surface water consumption met by snowmelt runoff, and intensity of shading indicates the average volume of surface water used for irrigation. Crops are ordered by their regional annual total irrigation surface water consumption, with higher total consumption to the right.

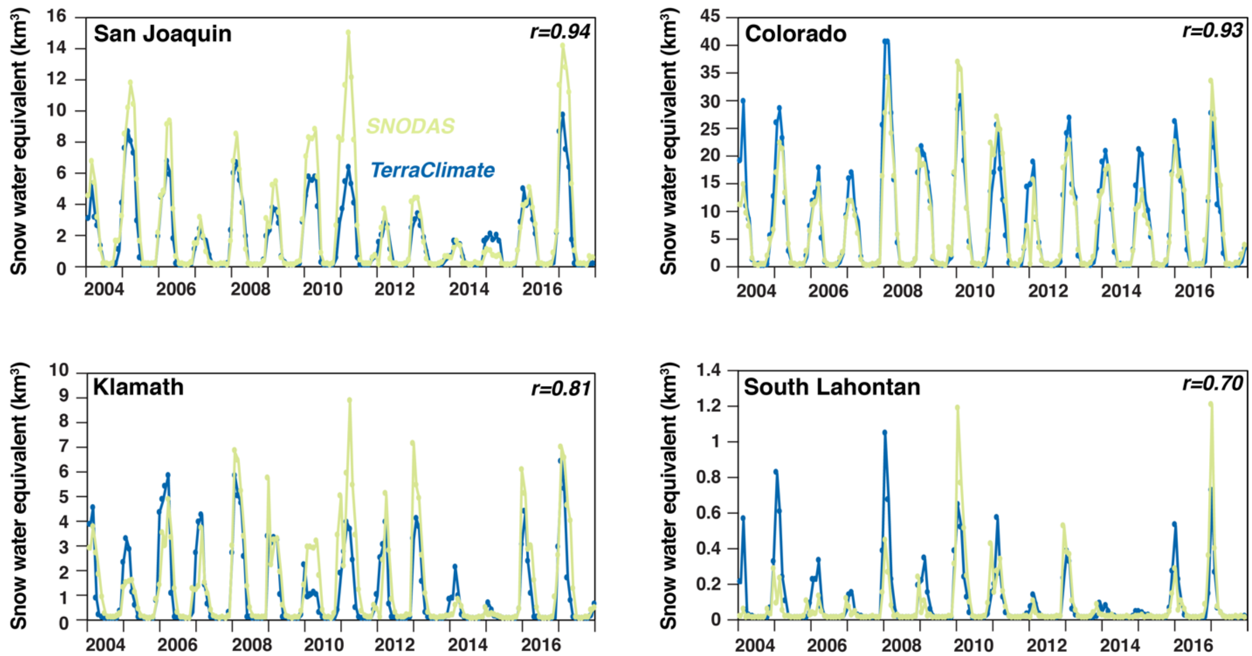


**Figure S7 | TerraClimate simulated monthly average snow water equivalent (SWE) in comparison to Snow Data Assimilation System (SNODAS) data.**

**Table S1. 2015 crop-specific irrigated and rainfed production (unit: tonnes/yr) for global basins.**

| Crops | IRR Snow[1] | IRR All[2] | RFD All[3] | TOT All[4] | IRR Share[5] | Snow IRR Share[6] | Snow TOT Share[7] |
|---|---|---|---|---|---|---|---|
| **cotton** | 1E+07 | 4E+07 | 3E+07 | 7E+07 | 54% | 37% | 20% |
| **wheat** | 8E+07 | 3E+08 | 5E+08 | 7E+08 | 35% | 33% | 12% |
| **grapes** | 7E+06 | 2E+07 | 5E+07 | 7E+07 | 30% | 30% | 9% |
| **millet** | 6E+05 | 2E+06 | 3E+07 | 3E+07 | 8% | 26% | 2% |
| **rapeseed** | 1E+06 | 5E+06 | 6E+07 | 7E+07 | 7% | 23% | 2% |
| **maize** | 6E+07 | 2E+08 | 7E+08 | 1E+09 | 24% | 23% | 6% |
| **rye** | 1E+05 | 6E+05 | 1E+07 | 1E+07 | 5% | 21% | 1% |
| **groundnuts** | 1E+06 | 1E+07 | 3E+07 | 4E+07 | 24% | 13% | 3% |
| **barley** | 2E+06 | 1E+07 | 1E+08 | 1E+08 | 9% | 12% | 1% |
| **citrus** | 8E+06 | 7E+07 | 7E+07 | 1E+08 | 50% | 11% | 6% |
| **sunflower** | 3E+05 | 3E+06 | 4E+07 | 4E+07 | 7% | 11% | 1% |
| **potatoes** | 1E+07 | 1E+08 | 2E+08 | 4E+08 | 33% | 11% | 4% |
| **rice** | 5E+07 | 5E+08 | 2E+08 | 7E+08 | 73% | 10% | 8% |
| **pulses** | 1E+06 | 2E+07 | 1E+08 | 1E+08 | 13% | 10% | 1% |
| **sugar cane** | 8E+07 | 9E+08 | 1E+09 | 2E+09 | 47% | 9% | 4% |
| **soybeans** | 1E+06 | 2E+07 | 3E+08 | 3E+08 | 5% | 8% | 0% |
| **sorghum** | 5E+05 | 7E+06 | 6E+07 | 6E+07 | 11% | 7% | 1% |
| **sugar beets** | 4E+06 | 8E+07 | 2E+08 | 2E+08 | 33% | 5% | 2% |
| **date palm** | 5E+03 | 4E+06 | 2E+06 | 6E+06 | 68% | 0% | 0% |
| **oil palm** | 0E+00 | 5E+04 | 3E+08 | 3E+08 | 0% | 0% | 0% |
| **cassava** | 0E+00 | 3E+05 | 3E+08 | 3E+08 | 0% | 0% | 0% |
| **cocoa** | 0E+00 | 2E+03 | 4E+06 | 4E+06 | 0% | 0% | 0% |
| **coffee** | 0E+00 | 2E+05 | 8E+06 | 8E+06 | 3% | 0% | 0% |

[1]IRR Snow: irrigated production in the most snow-dependent basins (the darkest blue basins in Fig.3); [2]IRR All: irrigated production in all basins; [3]RFD All: rainfed production in all basins; [4]TOT All: total (irrigated and rainfed) production in all basins; [5]IRR Share: share of irrigated production to total (irrigated and rainfed) production; [6]Snow IRR Share: share of irrigated production in the most snow-dependent basins to irrigated production in all basins; [7]Snow TOT Share: share of irrigated production in the most snow-dependent basins to total (irrigated and rainfed) production in all basins. Crops are ordered by their share of irrigated production in the most snow-dependent basins to irrigated production in all basins. Crop-specific production data are from the global crop water model (GCWM)[1] output adjusted by country-level FAO production data.

**Table S2. Reservoir capacity and alternative water demand for risky snow-dependent basins under both 2 Degree Celsius (2D) and 4 Degree Celsius (4D) warming scenarios.**

| Name | RC[1] ($km^3$) | ER[2] (Base, $km^3$) | ER[2] (2D, $km^3$) | ER[2] (4D, $km^3$) | AD[2] (Base, $km^3$) | AD[2] (2D, $km^3$) | AD[2] (4D, $km^3$) | RSI[3] (Base) | RSI[3] (2D) | RSI[3] (4D) |
|---|---|---|---|---|---|---|---|---|---|---|
| Alakol | 0 | 2.3 | 2.3 | 2.4 | 0.02 | 0.03 | 0.06 | ≫1 | ≫1 | ≫1 |
| Amu Darya | 15 | 56 | 54 | 52 | 9.5 | 9.9 | 12 | 0.64 | 0.66 | 0.78 |
| Central Nevada Desert Bains | 0 | 0.5 | 0.6 | 0.6 | 0.04 | 0.04 | 0.04 | ≫1 | ≫1 | ≫1 |
| Coastal Chile | 1.5 | 7.9 | 8.2 | 8.9 | 0.06 | 0.06 | 0.12 | 0.04 | 0.04 | 0.08 |
| Colorado | 38 | 11 | 11 | 12 | 0 | 0.26 | 0.63 | 0 | 0.02 | 0.05 |
| Columbia | 86 | 171 | 179 | 193 | 2.8 | 3.0 | 3.4 | 0.03 | 0.04 | 0.04 |
| Dzungarian | 0 | 1.1 | 1.2 | 1.8 | 0.36 | 0.39 | 0.42 | ≫1 | ≫1 | ≫1 |
| Escalante Desert-Sevier | 0.02 | 0.6 | 0.6 | 0.8 | 0.10 | 0.12 | 0.14 | 4.75 | 5.36 | 6.52 |
| Farah | 3.2 | 14 | 13 | 9.9 | 2.0 | 2.0 | 2.2 | 0.63 | 0.63 | 0.71 |
| Great Salt Lake | 4.6 | 1.8 | 2.1 | 2.5 | 0.72 | 0.77 | 0.82 | 0.39 | 0.38 | 0.32 |
| Ili | 32 | 12 | 13 | 16 | 0.09 | 0.20 | 0.33 | 0.01 | 0.02 | 0.02 |
| Kura | 24.0 | 23 | 20 | 17 | 0.88 | 1.3 | 1.8 | 0.04 | 0.07 | 0.10 |
| Lake Zaysa | 0.04 | 1.7 | 2.4 | 3.7 | 0.85 | 0.93 | 0.99 | 21 | 23 | 25 |
| Po | 2.7 | 33 | 31 | 29 | 0.0004 | 0.48 | 0.94 | 0.0002 | 0.18 | 0.35 |
| Rhone-Ebro | 18 | 49 | 45 | 40 | 0.72 | 1.2 | 1.7 | 0.04 | 0.07 | 0.09 |
| San Joaquin | 15 | 6.8 | 7.5 | 8.7 | 3.1 | 3.3 | 3.8 | 0.45 | 0.45 | 0.44 |
| Syr Darya | 37 | 36 | 39 | 47 | 8.3 | 9.1 | 9.5 | 0.23 | 0.24 | 0.26 |
| Tigris/Euphrates | 195 | 52 | 43 | 30 | 14 | 15 | 16 | 0.27 | 0.35 | 0.53 |

[1]RC: Reservoir capacity (data source: the Global Reservoir and Dam Database (GRanD) v1.3[2]); [2]ER: Annual excess runoff (runoff of snowmelt or rainfall not utilized in a given month); [3]AD: Alternative water demand (e.g., storage, inter-basin transfers, and desalination[3-6]); [4]RSI: Reservoir Storage Index: ratio of alternative water demand to reservoir water storage (the minimum between reservoir capacity and annual excess runoff). Note: reservoir water storage is not equivalent to the availability of alternative water due to competing reservoir water uses, seasonal fluctuations, and possible additional water supply from sources such as inter-basin transfer.

**Table S3. Basin average share of irrigation water consumption met by groundwater, and groundwater recharge rates for snow-dependent basins at risk under both 2 Degree Celsius (2D) and 4 Degree Celsius (4D) warming scenarios.**

| Name | Groundwater Share | Groundwater recharge rates |
|---|---|---|
| Alakol | 19% | < 100 mm/yr |
| Amu Darya | 5% | 99% area < 100 mm/yr |
| Central Nevada Desert Bains | 45% | < 100 mm/yr |
| Coastal Chile | 24% | < 100 mm/yr |
| Colorado | 32% | < 100 mm/ yr |
| Columbia | 30% | 73% area < 100 mm/yr |
| Dzungarian | 19% | < 100 mm/yr |
| Escalante Desert-Sevier | 21% | < 100 mm/yr |
| Farah | 35% | < 100 mm/yr |
| Great Salt Lake | 14% | < 100 mm/yr |
| Ili | 16% | < 100 mm/yr |
| Kura | 15% | 99% area < 100 mm/yr |
| Lake Zaysa | 17% | < 100 mm/yr |
| Po | 21% | > 100 mm/yr[1] |
| Rhone-Ebro | 31% | 45% area < 100 mm/yr |
| San Joaquin | 61% | 99% area < 100 mm/yr |
| Syr Darya | 6% | 99% area < 100 mm/yr |
| Tigris/Euphrates | 23% | 93% area < 100 mm/yr |

[1]Subsidence due to groundwater abstraction is already reported[2].

**Table S4. 23 CMIP5 climate models used for climate projections**

| Model Name | Model Agency and Country | Ensemble Used |
|---|---|---|
| ACCESS1-0 | Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM) (Australia) | ri1ip1 |
| ACCESS1-3 | Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM) (Australia) | ri1ip1 |
| bcc-csm1-1 | Beijing Climate Center; China Meteorological Administration (China) | r1i1p1 |
| bcc-csm1-1-m | Beijing Climate Center; China Meteorological Administration (China) | r1i1p1 |
| CanESM2 | Canadian Centre for Climate Modeling and Analysis (Canada) | r1i1p1 |
| CESM1-CAM5 | Community Earth System Model Contributors (United States) | ri1ip1 |
| CNRM-CM5 | National Centre of Meteorological Research (France) | r1i1p1 |
| CSIRO-Mk3-6-0 | Commonwealth Scientific and Industrial Research Organization/Queensland Climate Change Centre of Excellence (Australia) | r1i1p1 |
| GFDL-CM3 | NOAA Geophysical Fluid Dynamics Laboratory (United States) | ri1ip1 |
| GFDL-ESM2M | NOAA Geophysical Fluid Dynamics Laboratory (United States) | r1i1p1 |
| GFDL-ESM2G | NOAA Geophysical Fluid Dynamics Laboratory (United States) | r1i1p1 |
| GISS-E2-H | NASA Goddard Institute for Space Studies (United States) | ri1ip1 |
| GISS-E2-R | NASA Goddard Institute for Space Studies (United States) | ri1ip1 |
| HadGEM2-ES | Met Office Hadley Center (United Kingdom) | r1i1p1 |
| HadGEM2-CC | Met Office Hadley Center (United Kingdom) | r1i1p1 |
| inmcm4 | Institute for Numerical Mathematics (Russia) | r1i1p1 |
| IPSL-CM5A-LR | Institut Pierre Simon Laplace (France) | r1i1p1 |
| IPSL-CM5A-MR | Institut Pierre Simon Laplace (France) | r1i1p1 |
| IPSL-CM5B-LR | Institut Pierre Simon Laplace (France) | r1i1p1 |
| MIROC5 | Atmosphere and Ocean Research Institute, The University of Tokyo; National Institute for Environmental Studies; Japan Agency for Marine-Earth Science and Technology (Japan) | r1i1p1 |
| MIROC-ESM | Japan Agency for Marine-Earth Science and Technology; Atmosphere and Ocean Research Institute, The University of Tokyo; National Institute for Environmental Studies (Japan) | r1i1p1 |
| MIROC-ESM-CHEM | Japan Agency for Marine-Earth Science and Technology; Atmosphere and Ocean Research Institute, The University of Tokyo; National Institute for Environmental Studies (Japan) | r1i1p1 |
| MRI-CGCM3 | Meteorological Research Institute (Japan) | r1i1p1 |

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