Hydrologic responses to climate change and implications for reservoirs in the source region of the Yangtze River

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Background

As the third longest river in the world and the longest river in Asia, the Yangtze River (YZR) is extremely rich in water resources In particular, the upper reaches of the YZR have the world's largest reservoir group and hydropower production.

The source region of the YZR is located in the inland region within the Qinghai-Tibet Plateau with the components of alpine, glacier, frozen soil and snow, its hydrological cycle is thus extremely sensitive to global climate change.

The present study focuses on the Jinshajiang River basin (JRB), the source region of the YZR, aiming to: 1) quantitatively investigate the hydrological impacts of climate change in both the historical and projection periods by using multi-source observations and physical models; 2) demonstrate the hydrologic responses especially for the snowmelt process to climate change; 3) expand understanding of hydrological impacts of climate change to their implications for the hydraulic infrastructures.

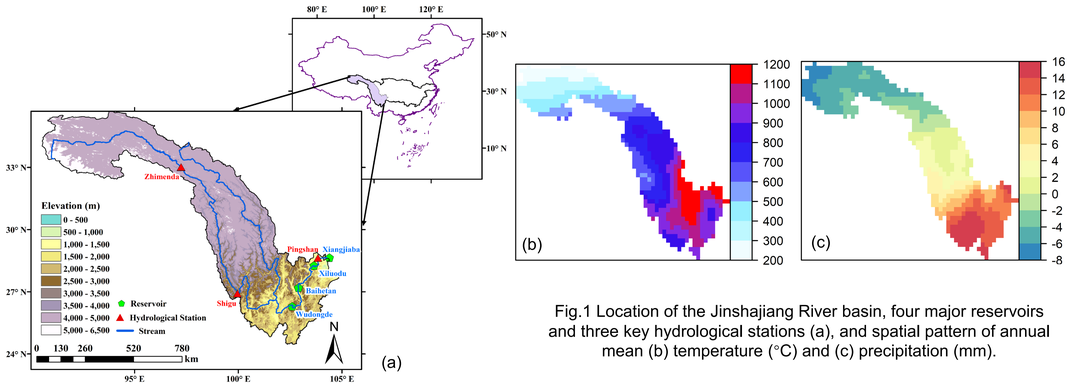


Fig.1 Location of the Jinshajiang River basin, four major reservoirs and three key hydrological stations (a), and spatial pattern of annual mean (b) temperature (°C) and (c) precipitation (mm).

Data and Method

Hydrological data

- **Three hydrological stations (Zhimenda, Shigu and Pingshan) on the main stream of the JRB, for daily streamflow observation covering the period from 1961 to 2015, and monthly naturalized streamflow covering the period from 2001-2010.**

Climate data

- **The CN05.1 gridded meteorological observation dataset (https://cerc.iap.ac.cn/resource) was constructed from over 2400 weather stations across China and interpolated to a resolution of 0.25° × 0.25° (Wu et al. 2017).**
- **Annual terrestrial evapotranspiration (ET) on 0.25° grid from Global Land Evaporation Amsterdam Model (GLEAM) covering the period from 1980 to 2020 (Martens et al. 2017).**
- **A remote sensing based composite 5 km resolution daily snow cover extent record over the Tibetan Plateau (TPSCE) from 1981 to 2016 (Chen et al. 2018).**
- **Climate projection from 14 GCMs under two emission scenarios (SSP2-4.5 and SSP5-8.5) were originally obtained from the latest CMIP6 archive.**

Hydrological model: SWAT was set up for the JRB based on DEM, soil, and land-use data at 1 km spatial resolution with a 1-day time step.
Model calibration and validation: The period 2001-2010 was used for calibration and 1961-2000 was used for validation. The temporal trend of key components of the water balance (e.g. precipitation, snowmelt, ET and streamflow) was tested with available observational and remote sensing data products

Quantifying the Hydrological Impacts

Tab.1 List of hydrological variables in abbreviation and their descriptions as used in the study.

Group	Abbreviation	Description	unit
Climate	T_{max}	Daily maximum temperature	°C
	T^{min}	Daily minimum temperature	°C
	PRECIP	Total amount of precipitation falling on the basin	mm
Snowmelt	SNOWR	Fraction of snowfall to total precipitation	%
	SNOMELT	Amount of snow or ice melting	mm
	SWE	Snow water equivalent	mm
Runoff	PERC	Water that percolates past the root zone	mm
	SURQ	Surface runoff contribution to streamflow	mm
	GWQ	Groundwater contribution to streamflow	mm
	WYLD	Water yield in the watershed	mm
Evapotranspiration	ET	Actual evapotranspiration	mm
Hydrological extremes	Q10	10 percentile annual daily mean flow	m^3/s
	Q50	50 percentile annual daily mean flow	m^3/s
	Q90	90 percentile annual daily mean flow	m^3/s
	Rx1d	Annual maximum 1-day peak flow	m^3/s
	Rx5d	Annual maximum 5-day peak flow	m^3/s
	Rx15d	Annual maximum 15-day peak flow	m^3/s
	Rx30d	Annual maximum 30-day peak flow	m^3/s
	SSI	Standardized streamflow index for 3-month scale	-

Results

Observed and projected climate change and hydrological impacts

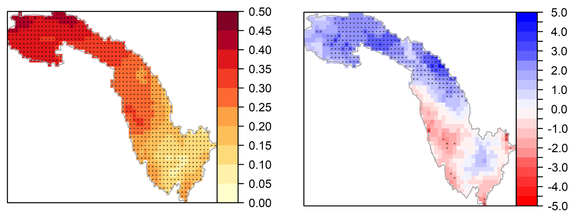


Fig.2 Spatial pattern of the trend in annual mean (a) temperature (℃per dacade) and precipitation (% per decade) in the Jinshajiang River basin from 1961 to 2015

Tab.2 Temporal trends of observed and climate-driven simulated annual 1-, 5-, 15- and 30-day peak flow and the annual low flow (Q10), median flow (Q50) and high flow (Q90) at three hydrological stations over 1961-2015 (m^3/s•yr).

Group	Station	Q10	Q50	Q90	Rx1d	Rx5d	Rx15d	Rx30d
Observed	Zhimenda	0.2	1.4	2.6	5.8	4.8	2.5	2.1
	Shigu	-1.1*	-0.9	-1.1	-6.2	-5.1	-5.9	-3.2
	Pingshan	7.2**	-1.2	-15.0	-36.0	-30.1	-33.7	-23.2
Simulated	Zhimenda	0.4	1.3	1.5	8.9	6.7	4.0	2.8
	Shigu	-0.1	-0.4	0.6	0.5	1.3	0.2	-1.5
	Pingshan	0.9	-0.8	-1.5	5.9	-4.5	2.2	3.2

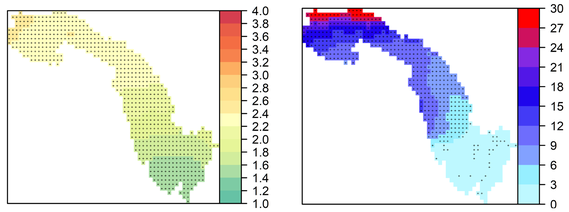


Fig. 3 Projected changes of annual mean temperature (℃) and precipitation (%) for the Jinshajiang River basin relative to 1961-2000 for 2021-2060 under SSP2-4.5.

Tab.3 Projected changes of ensemble mean in annual mean and extreme flows at three hydrological stations in the Jinshajiang River basin relative to the baseline period (1961-2000)

Scenario	Period	Station	Q10 (%)	Q50 (%)	Q90 (%)	Rx1d (%)	Rx5d (%)	Rx15d (%)	Rx30d (%)
SSP2-4.5	2021-2060	Zhimenda	24.7	13.3	13.5	24.5	23.9	21.6	21.8
		Shigu	10.5	15.2	11.1	13.5	12.7	12.5	12.3
		Pingshan	-0.9	7.1	4.4	10.6	7.9	5.6	4.8
	2061-2100	Zhimenda	28.4	17.8	15.4	36.6	29.6	25.8	23.8
		Shigu	13.7	19.9	18.2	25.6	24.0	20.9	20.1
		Pingshan	7.4	14.9	13.4	25.6	18.8	14.4	12.9

Hydrological response of climate change

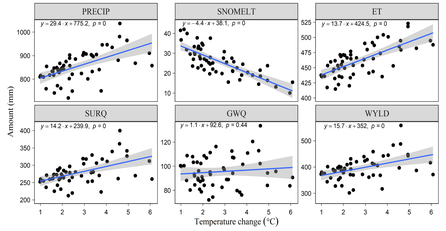


Fig.4 Response of water balance components to temperature increase in the Jinshajiang River basin.

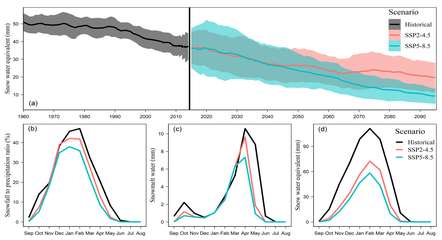


Fig.5 Temporal variations of snow hydrological components in the Jinshajiang River basin (a) trend of SWE, (b) snowfall/precipitation ratio, (c) snow melt water and (d) annual cycle of SWE.

Implications for Reservoirs

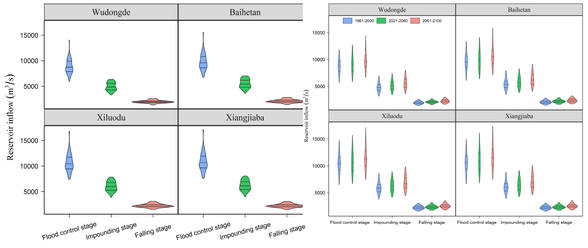


Fig.6 Distribution of reservoir inflows at each stage during a hydrologic year for four reservoirs in the Jinshajiang River basin during 1961-2015 and under SSP5-8.5.

Tab.4 Temporal trends of natural inflow for each reservoir over 1961-2015 (m^3/s•yr)

Reservoir	Flood control stage	Impounding stage	Falling stage
Wudongde	-1.1	-1.6	2.2
Baihetan	-1.3	-2.9	2.2
Xiluodu	-1.7	-3.6	2.1
Xiangjiaba	-1.5	-3.9	2.1

Qin Pengcheng, Xu Hongmei , et al. Hydrologic responses to climate change and implications for reservoirs in the source region of the Yangtze River. International Journal of Climatology, 2024, https://doi.org/10.1002/joc.8639