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Assessing the impacts of reservoirs on downstream flood frequency by coupling the effect of scheduling-related multivariate rainfall with an indicator of reservoir effects

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Supplementary Information

Estimation of the loss rate (%) of reservoir capacity

To estimate the variation of LR_i over time, it is assumed that there is the same amount of sediment in each year. Then, LR_i is estimated by

$$\mathrm{LR}_i = \frac{n_i \cdot L_i^m}{\mathrm{RC}_i} = \frac{n_i \cdot w_i^s \cdot \mathrm{Te}_i}{\rho \cdot \mathrm{RC}_i} \tag{S1}$$

where n_i is the number of years which the *i*-th reservoir has been used, L_i^m is the mean of annual loss of reservoir capacity (m^3) for the *i*-th reservoir, w_i^s is the mean of annual inflow sediment mass (kg) for the *i*-th reservoir, ρ is the density of the deposited sediment (kg/m^3) and Te_i is the trap efficiency (%). Based on the Brune method (Brune, 1953; Mulu and Dwarakish, 2015), the trap efficiency is estimated with reservoir capacity-inflow ratio as follows

$$\mathrm{Te}_i = 1 - \frac{0.5}{\sqrt{\mathrm{RC}_i / I_i^m}} \tag{S2}$$

where I_i^m is the mean of annual inflow volume in the *i*-th reservoir (m^3/day). The data in the previous literature (Guo, 1995; Hu, 2009; Liu, 2017) are collected to control the estimation errors of L_i^m. Please see Table S1.

Reference:

Hu, A. Y.: Analysis of sedimentation characteristics of Danjiangkou Reservoir, Research in Soil and Water Conservation, 16, 237-240, 2009. (In Chinese)

Brune, G. M.: Trap efficiency of reservoirs, Transactions American Geophysical Union, 34, 407-418, 1953.

Guo, J. M.: Analysis of sedimentation in Ankang Reservoir and its impact on the reservoir operation, Northwest Hydropower, 1995, 9-12, 1995. (In Chinese)

Liu, J. X.: Sedimentation characteristic analysis and desilting scheme optimization of Shiquan Reservoir, Pearl River, 38, 56-59, 2017. (In Chinese)

Mulu, A., and Dwarakish G. S.: Different approach for using trap efficiency for estimation of reservoir sedimentation, An Overview. Aquatic Procedia, 4, 847-852, 2015.

Table S1. Summary for the calculation of the mean of annual loss of reservoir capacity

Reservoirs	RC_i	I_i^m	w_i^s	Te_i	L_i^m (10^9 m^3)	
	(10^9 m^3)	(10^9 m^3)	(10^9 kg)	(%)	From previous studies	From Eq.(S2)*
Shiquan	0.566	11.73	12.6	88%	0.006	0.008
Ankang	3.21	19.17	27.1	94%	-	0.018
Huanglongtan	1.17	6.12	8.58	94%	0.007	0.006
Dangjiangkou	34.0	39.48	59.8	97%	0.044	0.042
Yahekou	1.32	1.09	-	98%	0.007	-

* $\rho = 1400$ kg/m^3

Table S2. Results of the change-point detection for the four MARI variables.

Variables	AK		HJG		HZ	
	change-point	p-value*	change-point	p-value	change-point	p-value
M	1976	1.037	1989	0.371	1971	1.278
I	1987	**0.031**	1985	**0.009**	1990	0.080
V	2009	0.746	1984	**0.042**	1984	0.769
T	1992	1.180	1984	0.986	1984	1.367

*Less than 0.05 is considered significant.

Figure S1. Interannual variation of loss rate of reservior capacitity for each reservoir in the study area.

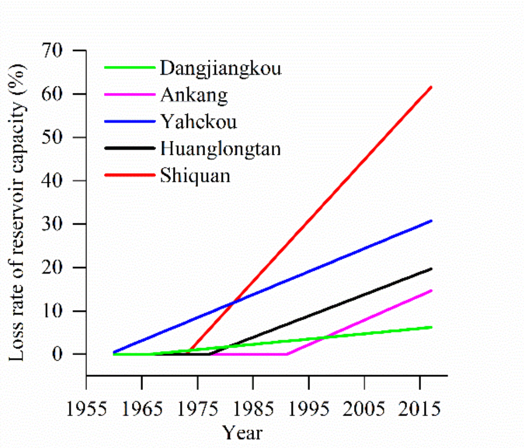


Figure S2. Impact of reservoir capacity loss on RI for AK, HJG and HZ stations.

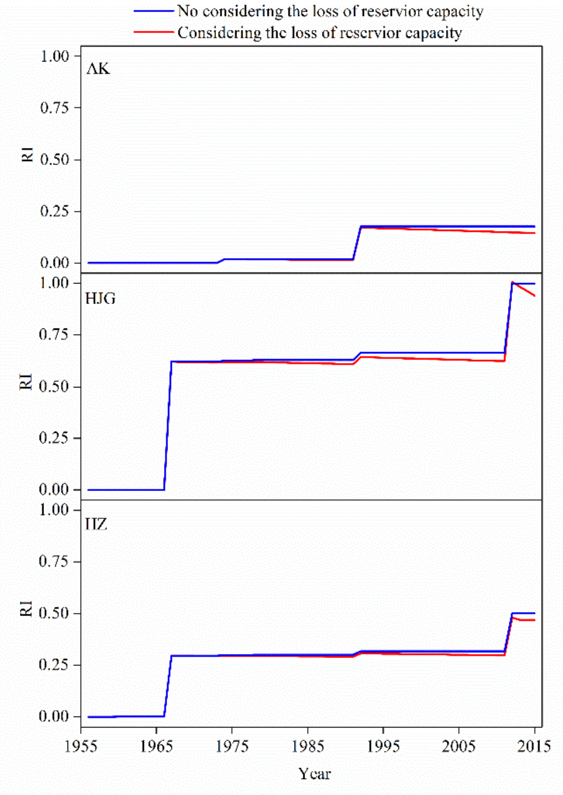
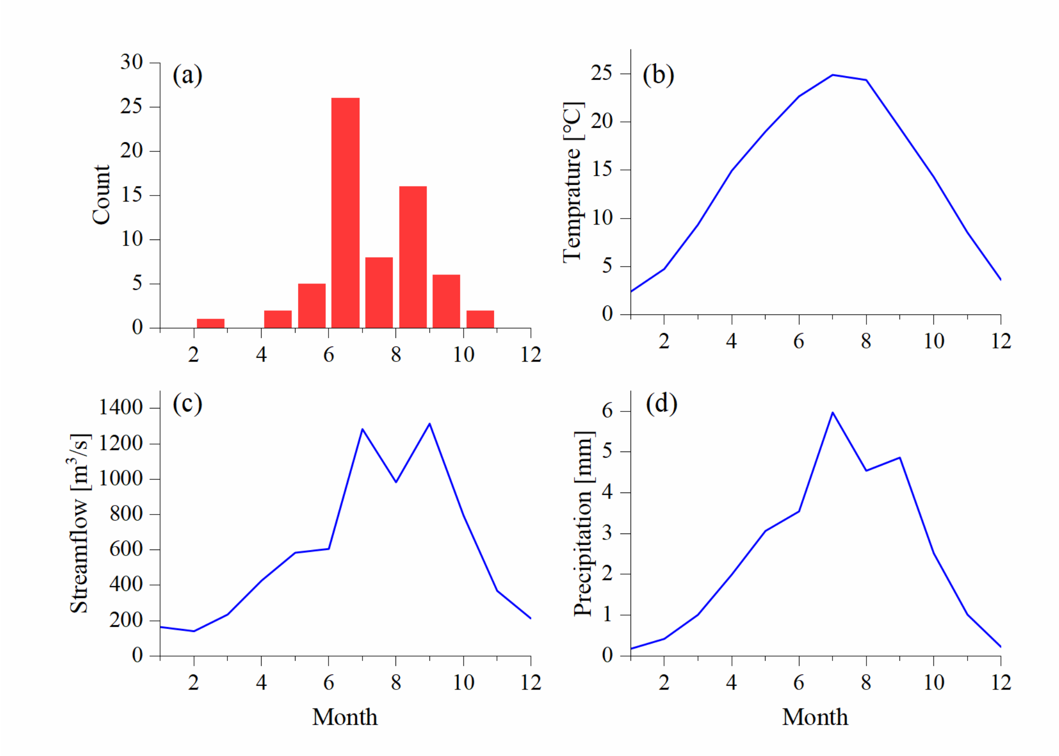


Figure S3. Preliminary analysis of the snowmelt influences on the streamflow in the catchment upstream the AK station. (a) is the total number of times for AMDF in each month; (b) is the monthly average temperature; (c) is the monthly average streamflow; and (d) is the monthly average precipitation.



Glossary and Notation:

$\alpha_0, \alpha_1, \beta_0, \beta_1$: parameters of nonstationary model.

A_i : total basin area upstream of the *i*-th reservoir.

A_T : total basin area upstream of the gauge station.

AIC: Akaike information criterion.

AK: Ankang (gauging station).

AMDF: annual maximum daily flow (series).

CDF: Cumulative distribution function

d : dimension of copulas.

df : freedom degree.

GA: Gamma distribution

GEV: Generalized Extreme Value distribution.

GEV_S23: nonstationary GEV distribution with the S23 scenario.

GML: generalized maximum likelihood (method).

GU: Gumbel distribution.

HJG: Huangjiagang (gauging station).

HZ: Huang zhuang (gauging station).

I : intensity, the mean of daily rainfall in MARI.

IDW: Inverse distance weighting method.

IRI: impounded runoff index, a ratio of reservoir capacity to mean annual runoff.

$\hat{l}$: maximized likelihood of the model object.

L : distance, the distance between the rainfall center and the outlet.

LOGNO: Lognormal distribution.

LR_i : loss rate (%) of total storage capacity of the *i*-th reservoir due to the sediment deposition.

μ_t : mu parameter of the distribution functions used.

M_c : length of the Markov chain.

M : maximum, the maximum of daily rainfall in MARI.

MARI: multiday antecedent rainfall input.

MCMC: Markov chain Monte Carlo.

ML: maximum likelihood (method).

n : number of data points.

N : total number of reservoirs upstream of the gauge station.

OR-JEP: OR-joint exceedance probability.

$P^{\vee}_{\mathrm{MARI}}$: OR-joint exceedance probability.

$\boldsymbol{\theta}_i$: parameter vector of the *i*-th marginal distribution.

$\boldsymbol{\theta}_c$: copula parameter vector.

$\boldsymbol{\theta}$: parameter vector of the whole *n*-dimensional distribution.

$\boldsymbol{\theta}_{\mathrm{GEV\_S23}}$: parameters of the GEV_S23 model.

$\hat{\boldsymbol{\theta}}^{i}_{\mathrm{GEV\_S23}}$: an estimation for the parameters of the GEV_S23 model.

$\bar{Q}$: mean annual runoff.

RRCI: rainfall-reservoir composite index.

RI: reservoir index.
RC: reservoir capacity.

RC_i : total storage capacity of the *i*-th reservoir.

σ_t : sigma parameter of the distribution functions used.

S0: constant scenario.

S1: RI-dependent scenarios.

S2: RRCI-dependent scenarios.

SBC: Schwarz Bayesian criterion.

T : timing, the end time of MARI in the year.

u_i : univariate marginal distribution of X_i.

V : volume, the total of daily rainfall in MARI.

WEI: Weibull distribution.

ξ : shape parameter of the Generalized Extreme Value distribution.

$X_1, X_2, ...X_d$: scheduling-related MARI variables.