Spatiotemporal heterogeneity and attribution of **baseflow** in the source region of the Yangtze River (**SRYR**)

Guangdong Wu（吴光东）
Changjiang River Scientific Research Institute
（长江科学院）

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Spatiotemporal heterogeneity and attribution of baseflow in the source region of the Yangtze River——Background

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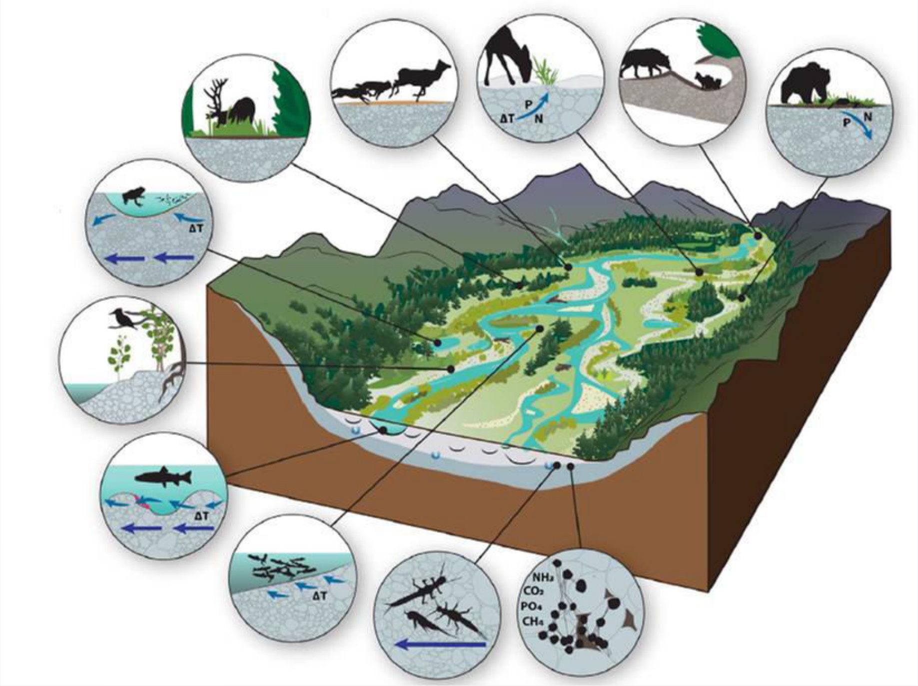

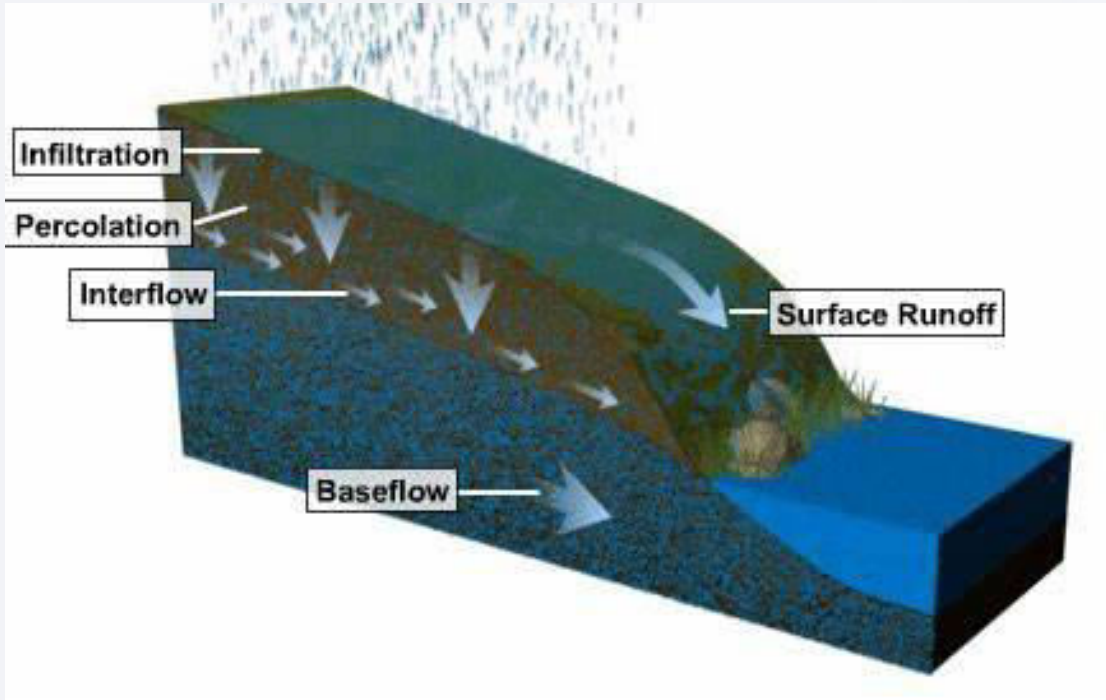

Images of low-flow and base-flow in Virginia streams , Kappahunnouh County stream.

Definition: Baseflow (also called drought flow, groundwater recession flow, low flow, low-water flow, low-water discharge and sustained or fair-weather runoff) is the portion of the streamflow that is sustained between precipitation events, fed to streams by delayed pathways. It should not be confused with groundwater flow. Fair weather flow is also called base flow.

Significance: It carries substantial significance for the health and stability of river and lake ecosystems.

The role of baseflow is frequently underestimated: Ahiablame et al. (2017) pointed out that 60% of streamflow in the Missouri River basin is derived from baseflow. The simulation results from Miller et al. (2016) show that 56% of the surface water in the Upper Colorado River Basin originated as base flow.

Previous studies on baseflow have primarily focused on temperate rivers, with some coverage of cold-region rivers such as those in the Arctic, Alaska in the United States, and the European Alps. However, due to cold temperatures, oxygen deficiency, and limited accessibility, there is essentially a lack of research related to rivers on the Qinghai-Tibet Plateau.

Spatiotemporal heterogeneity and attribution of baseflow in the source region of the Yangtze River——Study area

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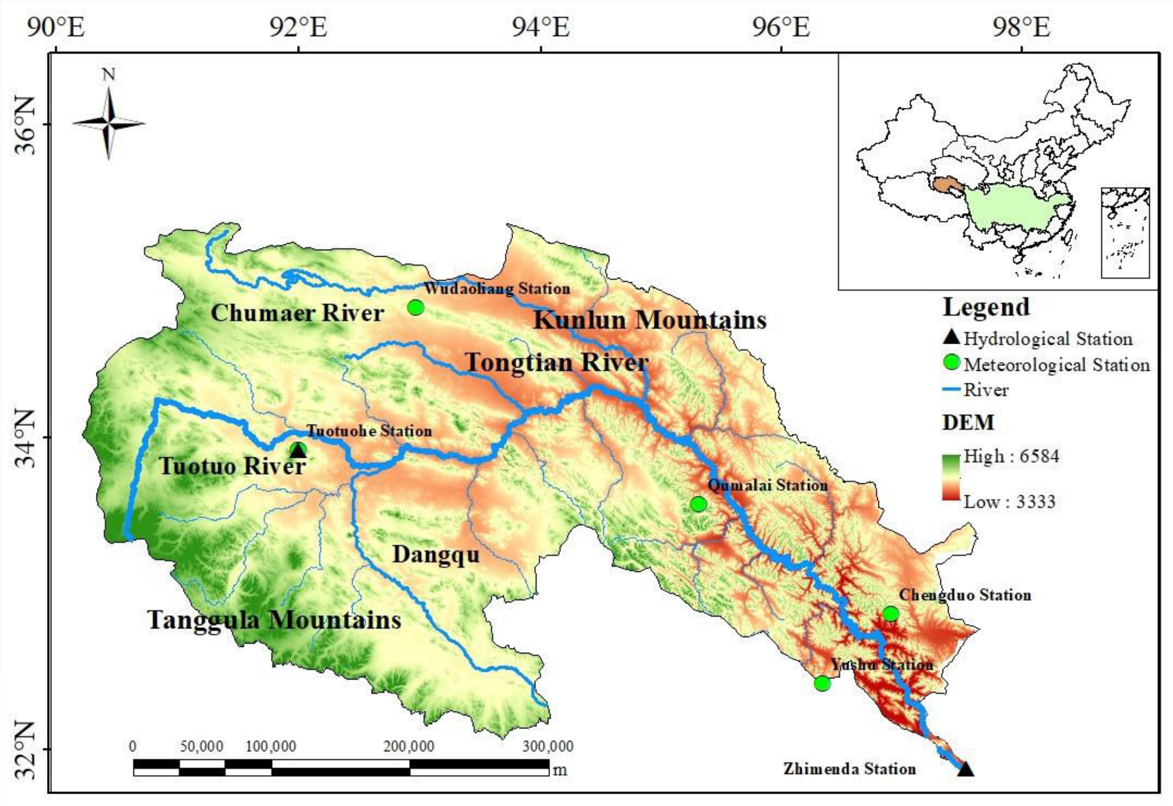


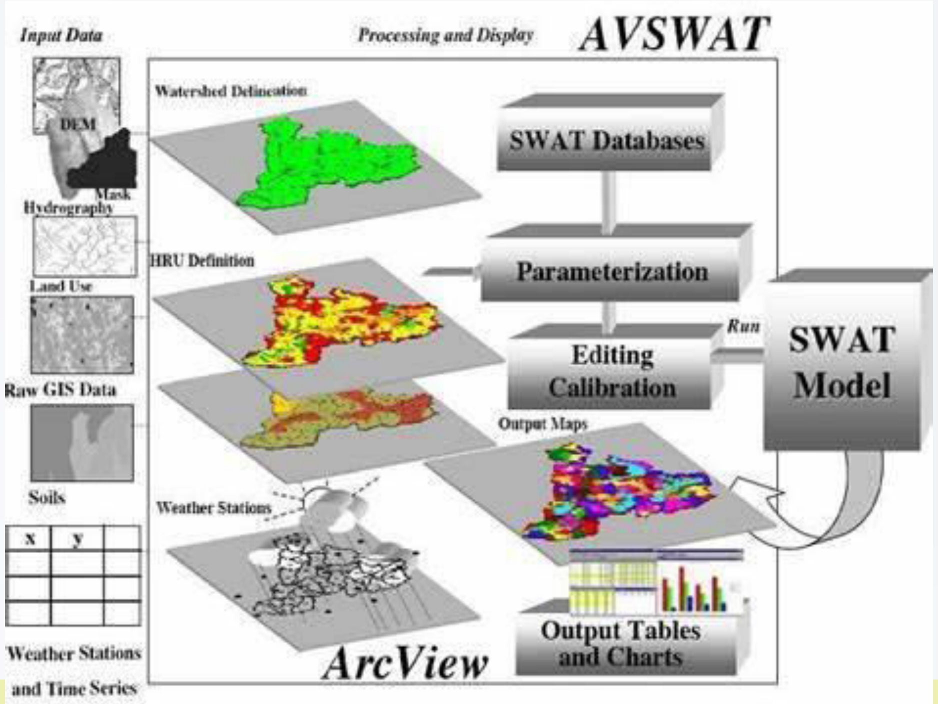
- The SRYR consists of the **Tuotuo River**, **Dangqu River**, the **Chumal River**, and the **Tongtian River**.
- The total length of the main stream of the Tongtian River is 1174km, with a catchment area of $13.77 \times 10^4 km^2$, accounting for 7.6 percent of total area of the Yangtze River catchments.
- The source region has an average altitude of **4500m** above sea level, with the highest point reaching 6486m.
- This area is dominated by unique plateau climates, with an average annual temperature ranging from **-17℃ to -5.5℃**.
- Annual precipitation ranges from **250 to 600 mm**.
- The vegetation that covers the headwaters primarily consists of three types: alpine meadow, grassland, and marsh. The ecosystem is of simple structure, poor resilience, and low self-recovery ability, and once the ecological environment is damaged, an ecosystem collapse may occur.

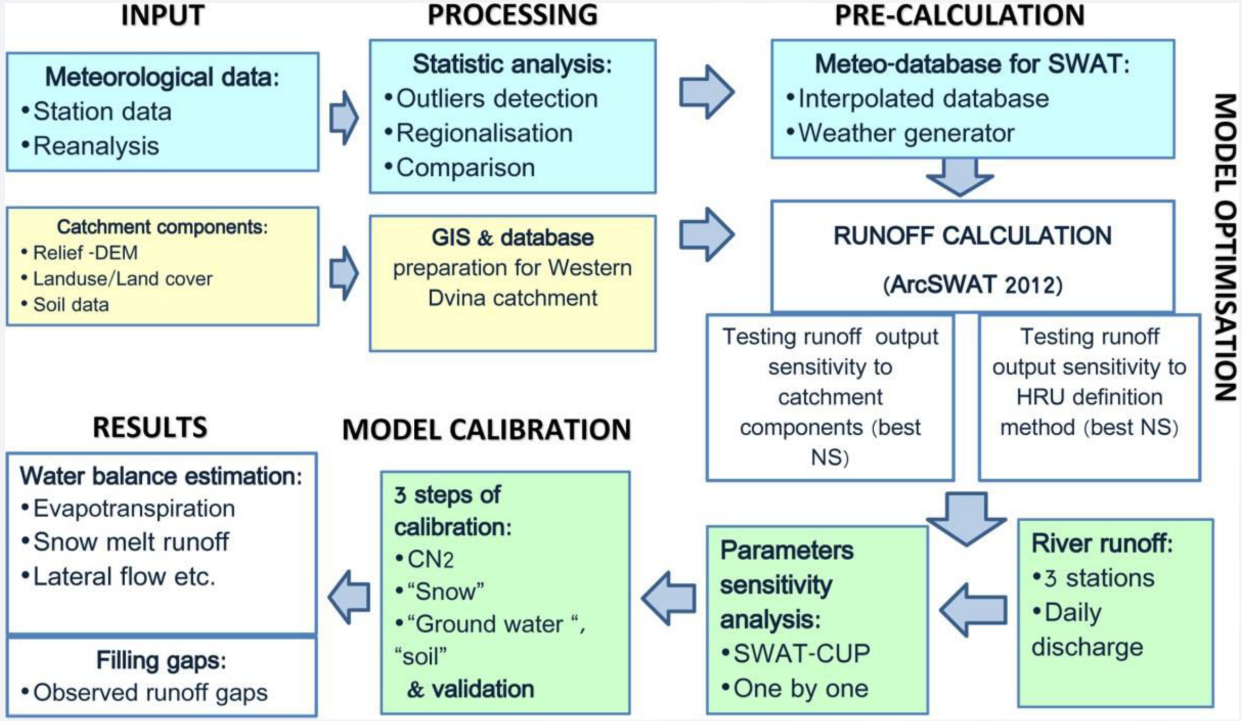
- Under the joint influences of climate change and anthropogenic disturbance, **problems like accelerated permafrost melting, grassland degradation, soil erosion, and land desertification directly threaten the stability of the rivers' ecosystems** and has recently been recognized as a serious social concern. Moreover, supra-permafrost water has become a major source of surface water at the Zhimenda and Tuotuohe stations, implying that **the Yangtze River Water Tower has become increasingly unstable**. To prevent further degradation, in 2005, China's State Council invested 7.5 billion yuan RMB to implement **more than 22 ecological restoration programs** in the Sanjiangyuan Nature Reserve, covering the headwaters of the Yangtze River, the Yellow River, and the Lancang.

SWAT model construction

SWAT is…

- One of the most widely-used watershed scale simulation tools
- Used around the world to address watershed questions
- Published in thousands of peer-reviewed scientific articles





Some reasons the SWAT Model is so widely used

- ✓ Can predict the effect of soil, land use, and management on water and water quality
- ✓ Physically based
- ✓ Computationally efficient
- ✓ Uses readily-available inputs
- ✓ Well-documented, with several users manual and a theoretical manual
- ✓ Open source, which means that the algorithms are available to all

Spatiotemporal heterogeneity and attribution of baseflow in the source region of the Yangtze River——Methods

Baseflow separation approaches

- Two-parameter digital filtering method
- BFI methods
  - the standard BFI(f) method
  - the modified BFI(k) method
- HYSEP methods
  - the fixed interval method
  - the sliding interval method
  - the local minimum method
- PART methods

Baseflow evaluation criterion

(Since the applicability of the baseflow separation methods differed in various regions, it is necessary to evaluate their practicalities in the SRYR.)

Considering that baseflow is relatively stable, the reliability of annual separated baseflow can be assessed using the standard deviation and extreme value ratio of the BFI series. Additionally, strict baseflow points are selected as baseflow references (considered to be true values). We evaluate the accuracies using the Nash-Sutcliffe Efficiency (NSE) and Kling-Gupta Efficiency (KGE).

Trend and breakpoints detecting

The trend in baseflow and its corresponding predictors at annual or seasonal scales from 1957 to 2020 can be estimated using the non-parametric Mann-Kendall test, the Sen' s Slope test, and linear regression analysis.

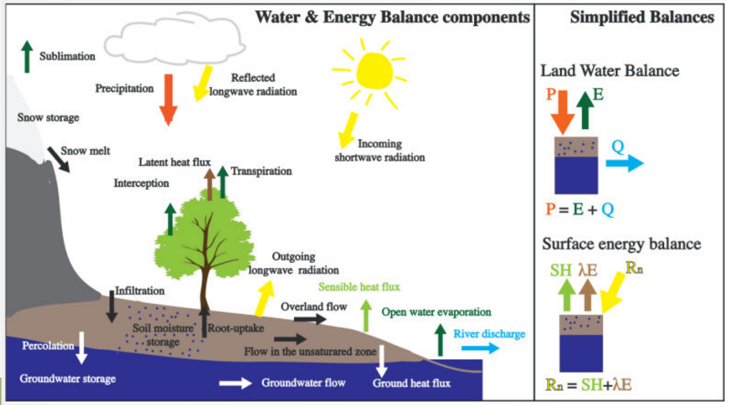
Correlation Analyses

The correlation between baseflow and its potential influencing factors is evaluated using the Spearman correlation analysis.

Attribution analysis of baseflow

We use the elasticity approach to quantify the relative contributions of climate factors and human activities to changes in baseflow.

Budyko framework



Spatiotemporal heterogeneity and attribution of baseflow in the source region of the Yangtze River——Temporal variation of baseflow

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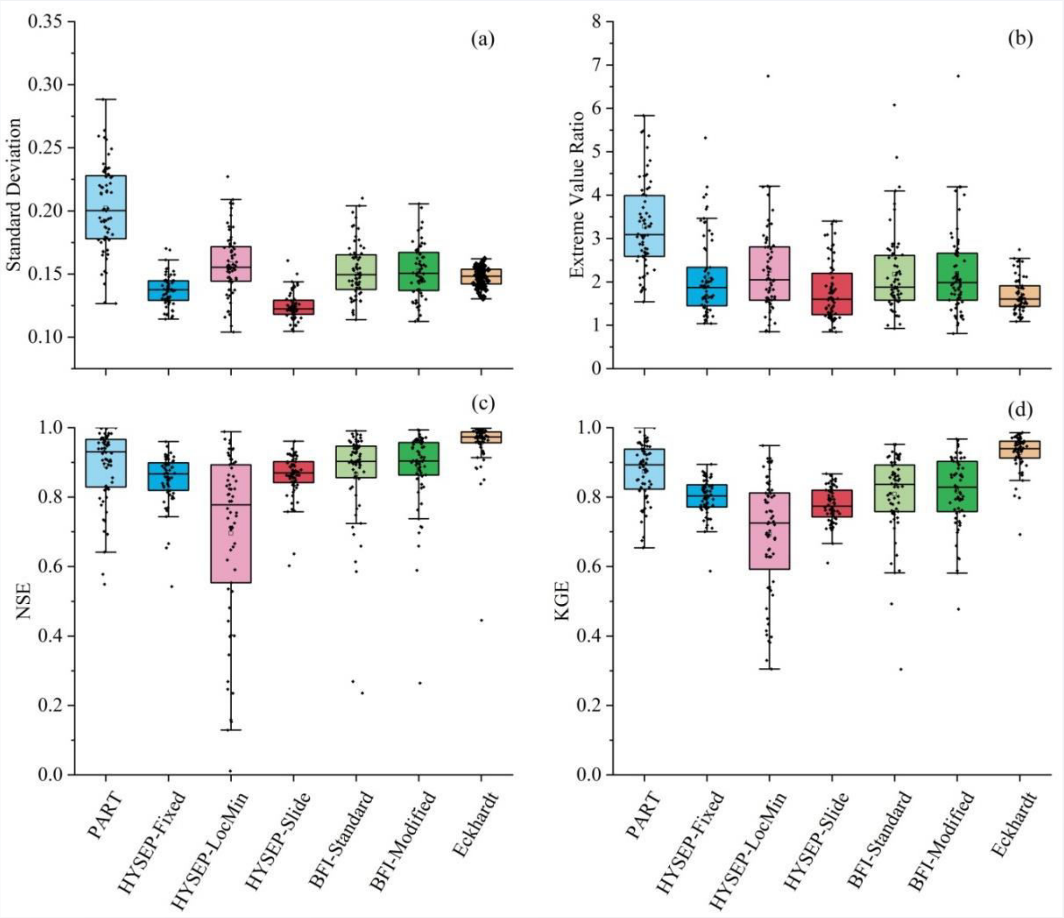
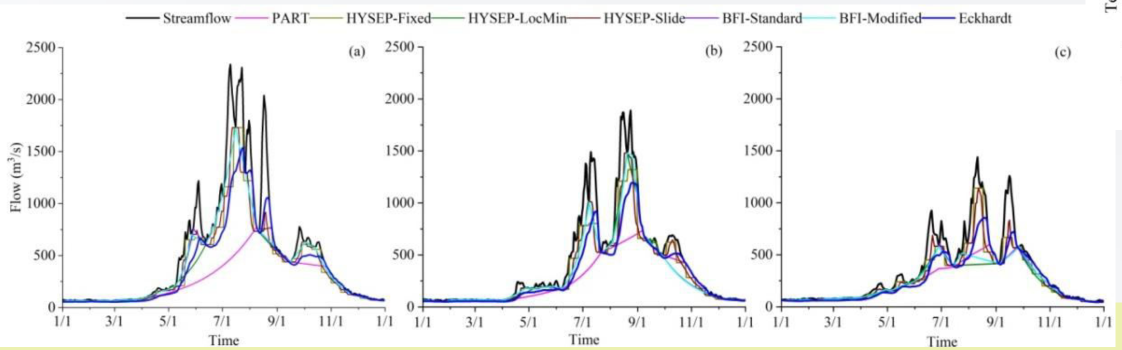
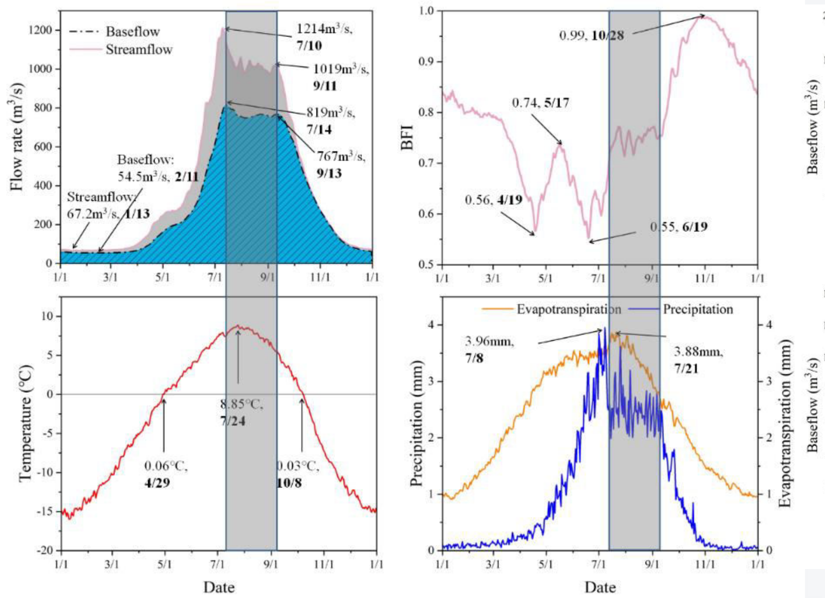
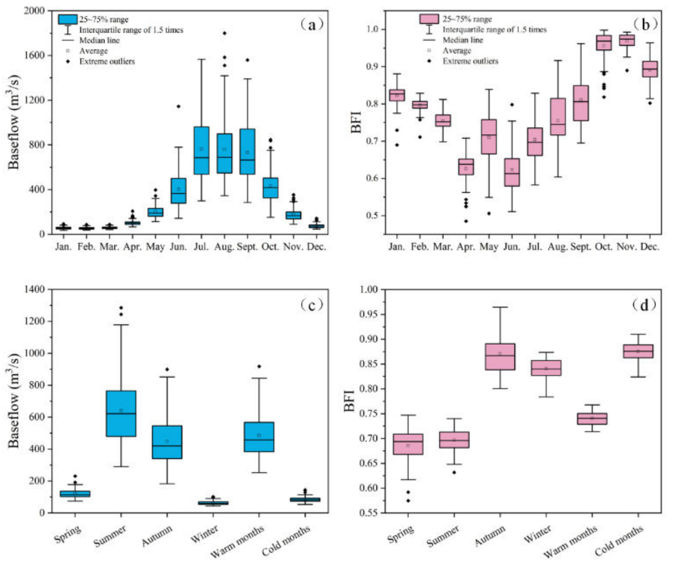


- The Eckhardt method has the lowest median and mean of the extreme value ratio, and produces the largest NSE/KGE mean (0.96/0.93) and median (0.97/0.94).
- **The Eckhardt method** is the most suitable and reliable method for baseflow separation in the SRYR.



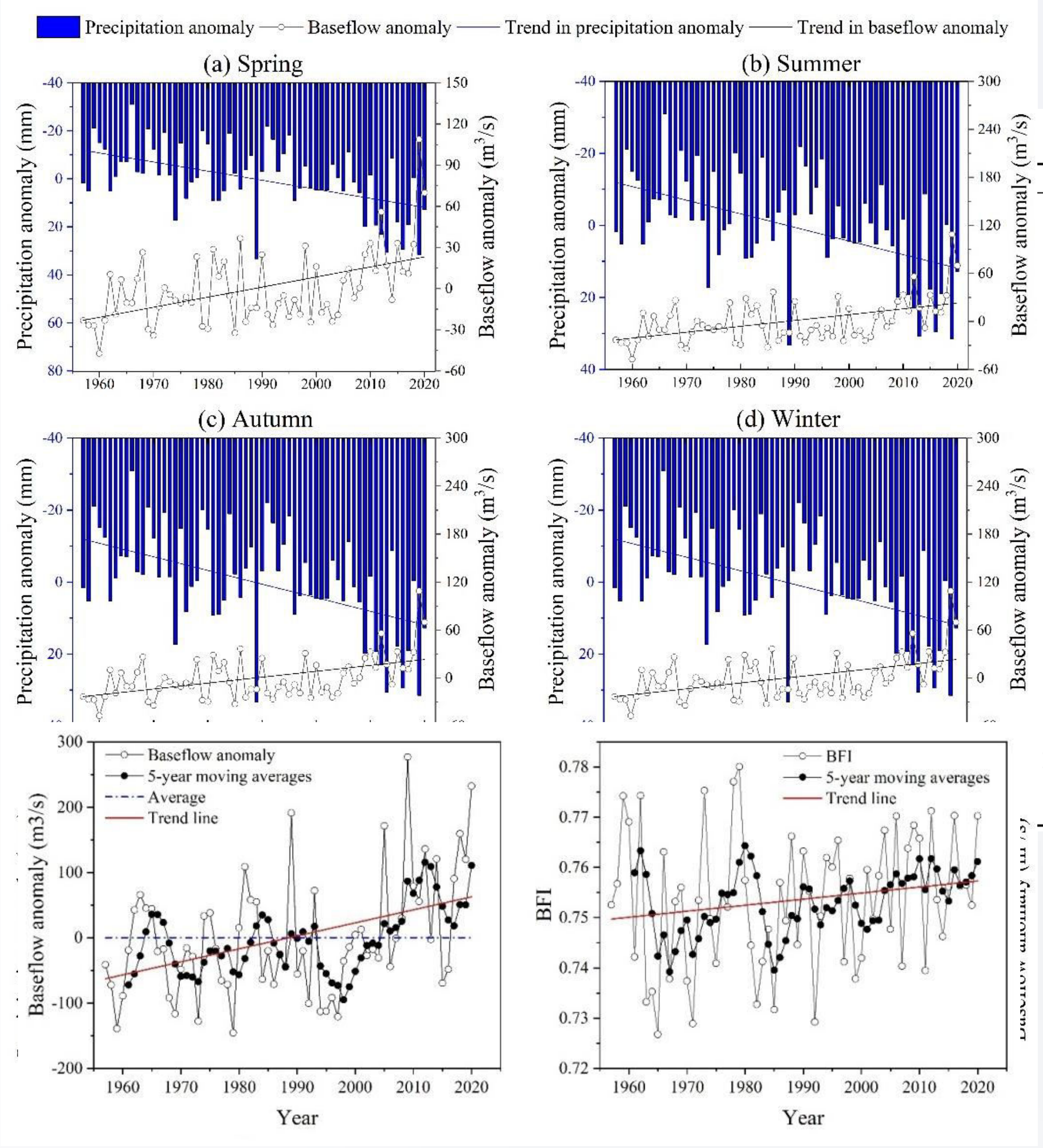
Intra-annual distribution of baseflow and BFI





Baseflow and BFI present distinct intra-annual distribution patterns, namely that baseflow follows the unimodal distribution, while BFI is in bimodal distribution.

Spatiotemporal heterogeneity and attribution of baseflow in the source region of the Yangtze River——Temporal variation of baseflow



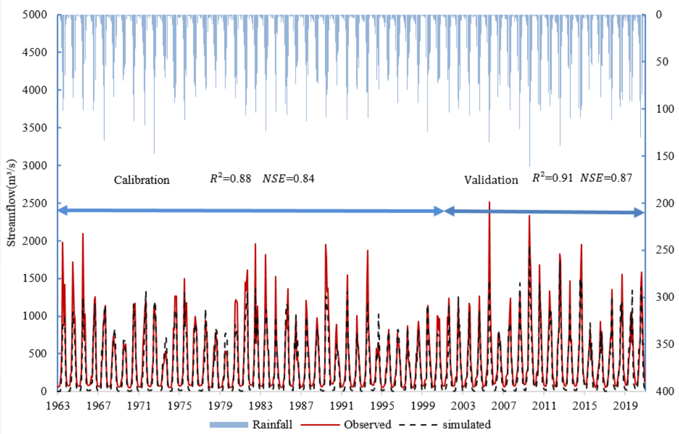
Temporal variability of annual/seasonal baseflow/BFI

Table 1.Long-term trend and breakpoints detecting results of annual and seasonal baseflow, BFI, and climate predictors.

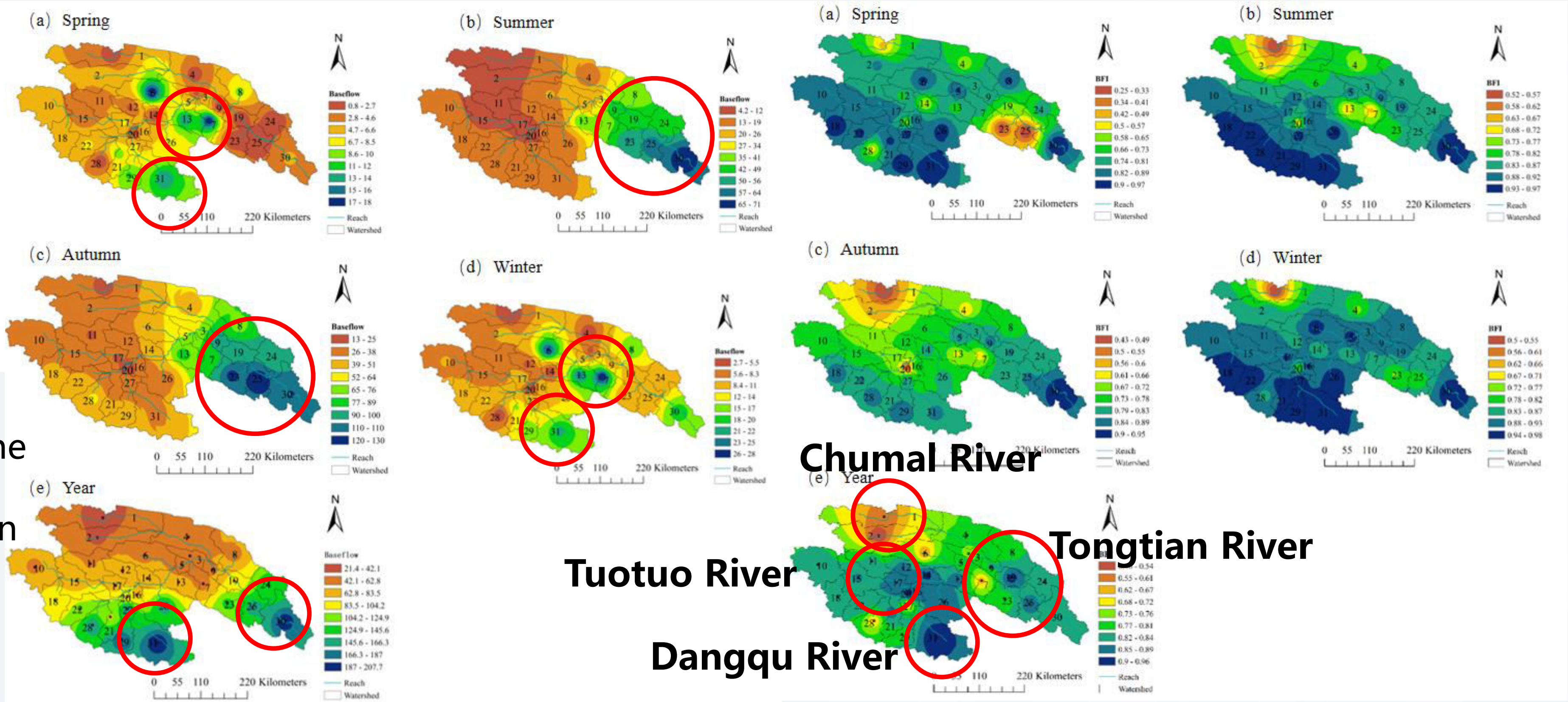
		Annual	Spring	Summer	Autumn	Winter	Warm months	Cold months
Baseflow	Z	2.80	3.81	2.30	2.51	3.51	2.73	4.22
	Trends	↑	↑	↑	↑	↑	↑	↑
	Trend magnitude in $m^3s^{-1}yr^{-1}$	1.69	0.62	2.94	3.04	0.25	2.61	0.45
	Abrupt point	1998	2004	1998	2002	2004	1998	2004
BFI	Z	1.60	-0.3	0.89	-0.10	1.12	1.43	1.65
	Trends	NS	NS	NS	NS	NS	NS	NS
	Trend magnitude in yr^{-1}	/	/	/	/	/	/	/
	Abrupt point	2000	/	/	/	2006	2000	2006
Precipitation	Z	2.9374	3.7485	1.6048	1.7091	1.1761	2.7983	2.9142
	Trends	↑	↑	NS	NS	NS	↑	↑
	Trend magnitude in mm yr^{-1}	1.14	0.35	0.50	0.25	0.03	1.02	0.10
	Abrupt point	1998	1995	2001	1994	1984	1998	1980
Temperature	Z	6.9002	4.8261	5.4634	5.6488	5.417	6.4947	6.1586
	Trends	↑	↑	↑	↑	↑	↑	↑
	Trend magnitude in ℃ yr^{-1}	0.036976	0.025956	0.028956	0.041508	0.043095	0.02949	0.046467
	Abrupt point	1997	1995	1994	2000	2001	1994	2001
Evapotranspiration	Z	2.2537	0.74738	0.97912	0.9096	3.6094	1.292	3.1807
	Trends	↑	NS	NS	NS	↑	NS	↑
	Trend magnitude in mm yr^{-1}	0.61112	0.10866	0.11814	0.096997	0.29683	0.29735	0.41488
	Abrupt point	1969	1969	1968	1968	2001	1968	2001

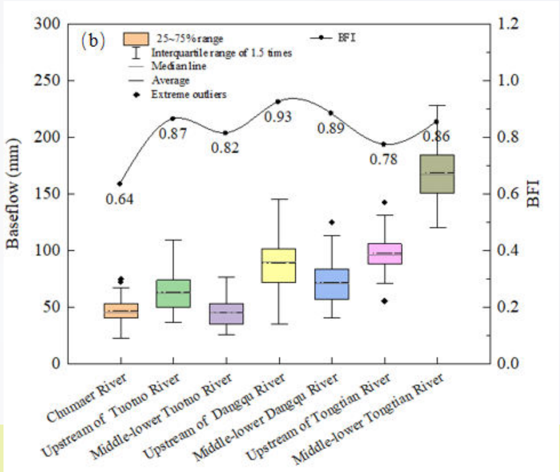
- The annual and seasonal baseflow have statistically significant increasing trends, and the significance of baseflow in spring and winter is greater than that in summer and autumn.
- Though the annual BFI, in both warm and cold months, has gradual increasing trends from 1957 to 2020, their trends are not statistically significant.

Spatiotemporal heterogeneity and attribution of baseflow in the source region of the Yangtze River——Spatial heterogeneity of baseflow



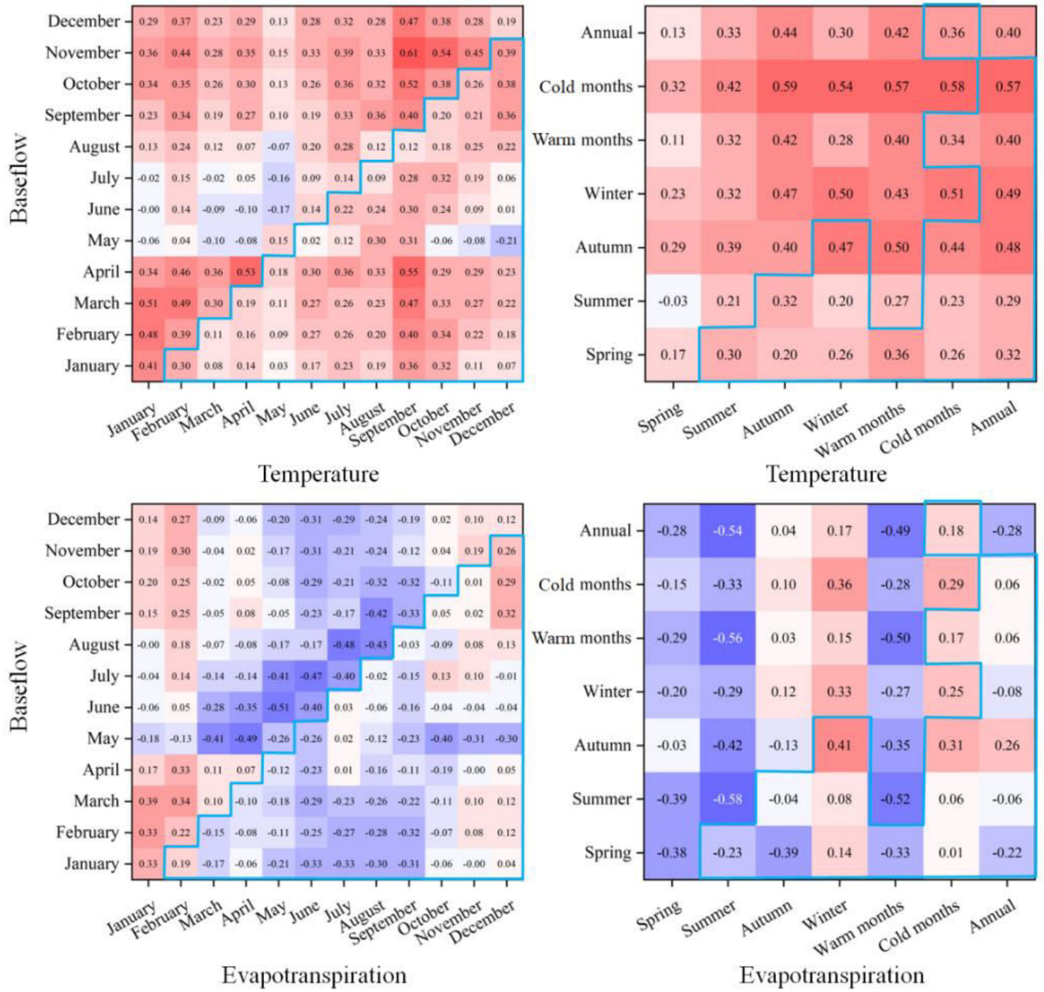
The determination coefficient (R2) and efficiency coefficient (NSE) of the simulated and measured monthly average runoff during the calibration and validation periods of the model attain values of 0.88 and 0.84, and 0.91 and 0.87, respectively.

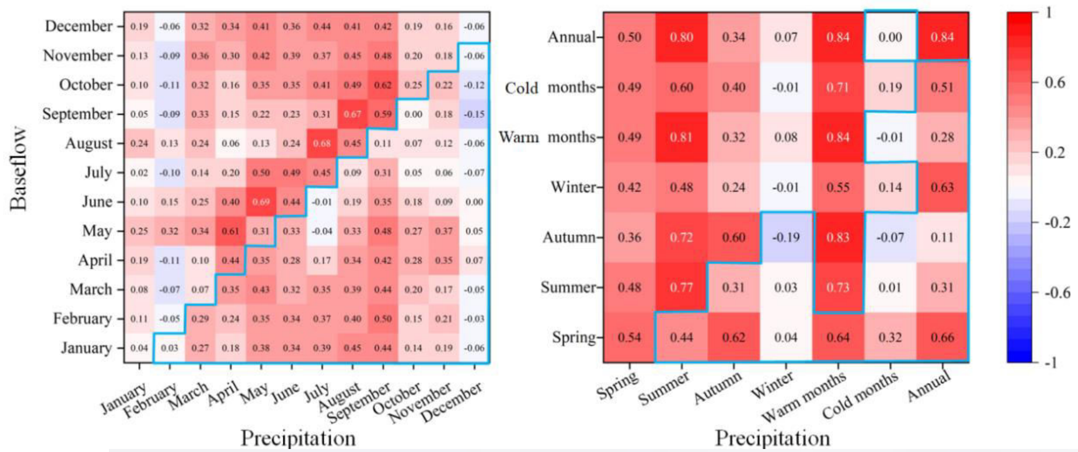


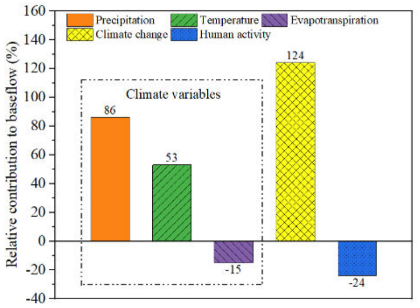


- The spatial distribution of baseflow in spring and winter is generally consistent, and both the upper Dangqu and Tongtian River exhibit higher baseflow values compared to other regions of the SRYR. In summer and autumn, the baseflow in the middle and lower reaches of the Tongtian River is higher than that in other regions. The annual baseflow is relatively higher in the southern and eastern region of the SRYR, surpassing 100mm. In particular, the upstream of Dangqu and downstream of Tongtian River exhibit baseflow values exceeding 180 mm.
- The Dangqu River exhibits the highest BFI, followed by the Tuotuo River and the Tongtian River, while the Chumal River has the lowest BFI.

Spatiotemporal heterogeneity and attribution of baseflow in the source region of the Yangtze River——Attribution of baseflow variation







The depth of color represents the magnitude of the correlation coefficient, with red indicating positive correlation and blue indicating negative correlation.

- The roles of precipitation, temperature, and evapotranspiration are distinct in spring, summer, autumn, and winter. **Precipitation** is the most critical driver in contributing to the change in baseflow, followed by temperature, and then evapotranspiration.
- The contributions of precipitation, temperature, evapotranspiration, and ecological conservation programs on baseflow are 86%, 53%, -15%, and -24%, respectively.

- However, **across the four seasons, these three predictors play different roles in influencing baseflow**. Precipitation makes the greatest contribution in spring and summer, followed by evapotranspiration, then temperature. In autumn, precipitation and temperature make the greatest two contributions, followed by evapotranspiration. In winter, temperature makes the greatest contribution, followed by evapotranspiration. The contribution of precipitation is so minute that it can be overlooked.

Spatiotemporal heterogeneity and attribution of baseflow in the source region of the Yangtze River——Underlying mechanism

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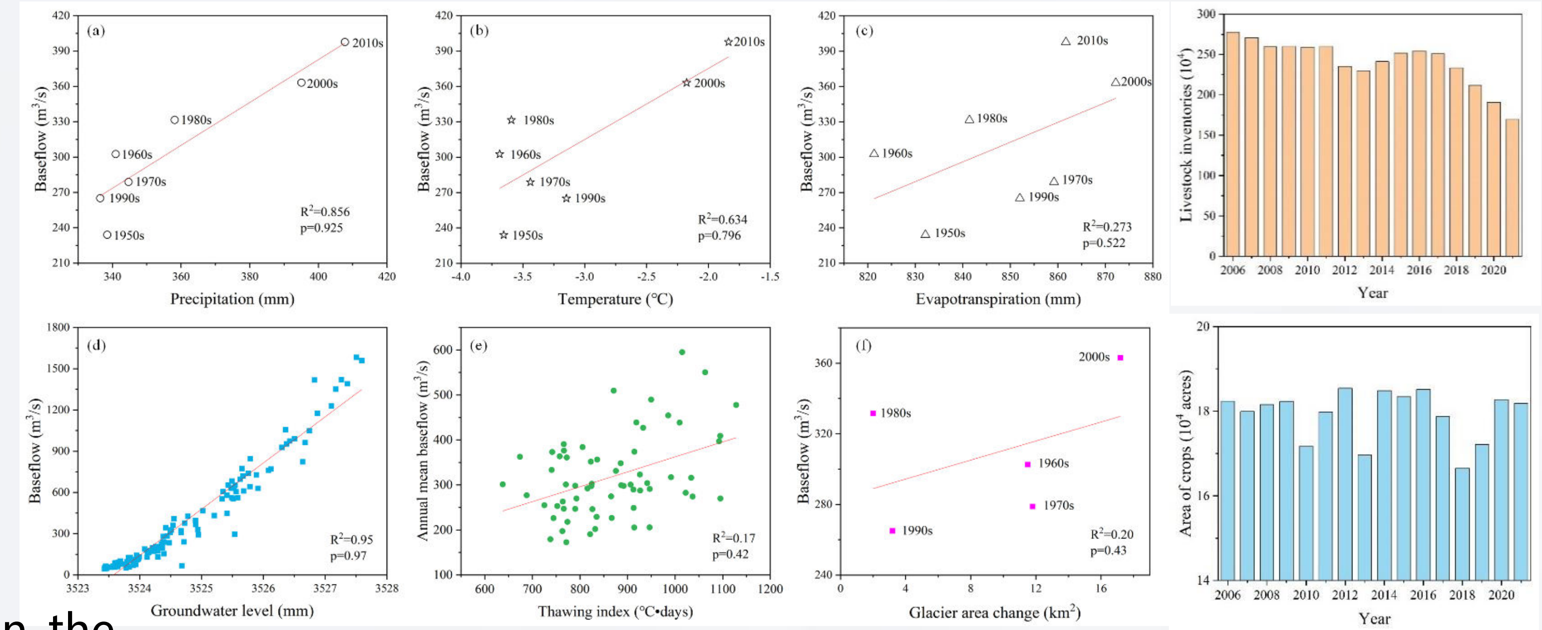
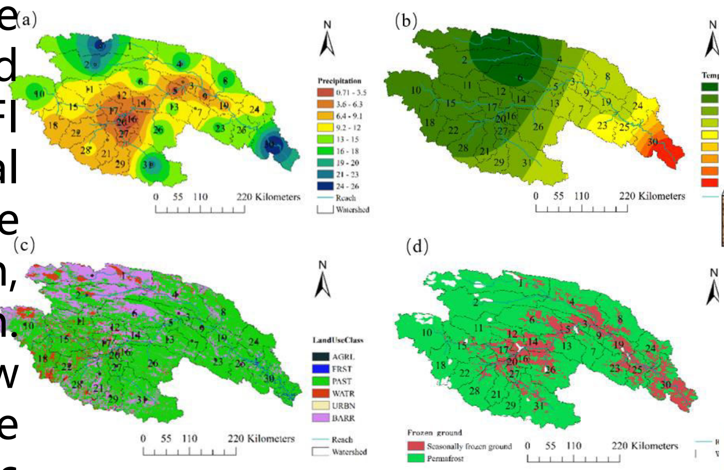
Temporal variation

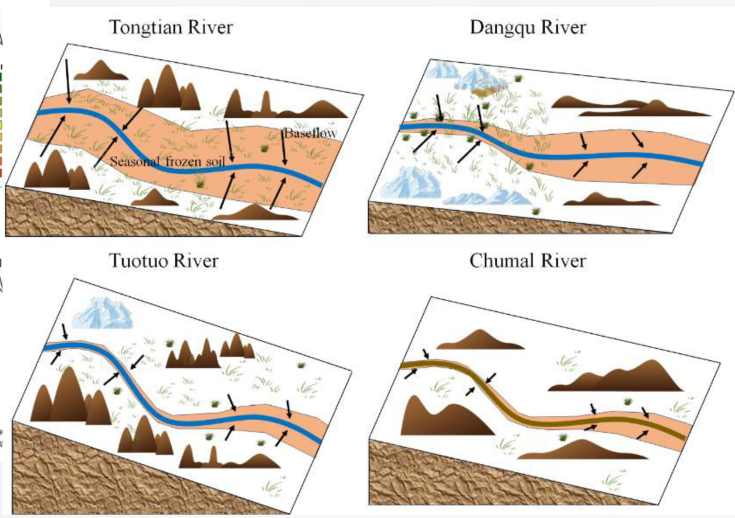
The glacier/permafrost melting water and snowmelt associated with increasing temperature, in addition to the increasing precipitation inputs, drive the increase in groundwater discharge, albeit under the negative influence of evapotranspiration and ECPs implementations. The variation of baseflow is the result of the combined effect of the aforementioned factors.



Spatial heterogeneity

Higher baseflow and BFI values are observed in the upstream region of Dangqu, attributed to the hydrological contribution of the Chadan Wetland within the SRYR. In contrast, lower baseflow and BFI values are prevalent in the upstream of the Chumal River. This phenomenon is attributed to the predominance of barren land cover in this region, resulting in restricted baseflow generation. Additionally, distinct zones with higher baseflow values are identified in the upper reaches of the Tongtian River and Dangqu River. This pattern is plausibly linked to the extensive occurrence of seasonal frozen soil within these geographical sectors.





- Our results highlight the critical roles of both precipitation and temperature. They also indicate that climate change, rather than ecological conservation programs (ECPs), dominated the variation in baseflow in the SRYR. In brief, temporal trends in baseflow can be generally explained by an increase in temperature, the superimposition of which is likely to become more influential on precipitation in the future.

- Spatially, the variation patterns of baseflow and BFI values have **distinct watershed characteristics in the SRYR**. Overall, the Dangqu River demonstrats the highest BFI, the Tongtian River displays the largest baseflow, and the Chumal River exhibits the lowest baseflow and BFI.

- The rise in baseflow suggests the groundwater storage is increasing, but that is not necessarily a good thing. The observed increase in temperature in recent years poses a much bigger crisis to the stability of the Asian water tower, in conjunction with the ongoing glacier retreat and permafrost degradation.

Thank you for your listening, and please welcome the criticisms！

Guangdong Wu (吴光东) Contact information

Telephone: 18164260805

Email: wugd@mail.crsri.cn