2024 Annual INARCH Workshop, Lanzhou and Zhangye, China, October 14–19, 2024

Variation of Riverine Sediment Transport in River Basins on the Tibetan Plateau

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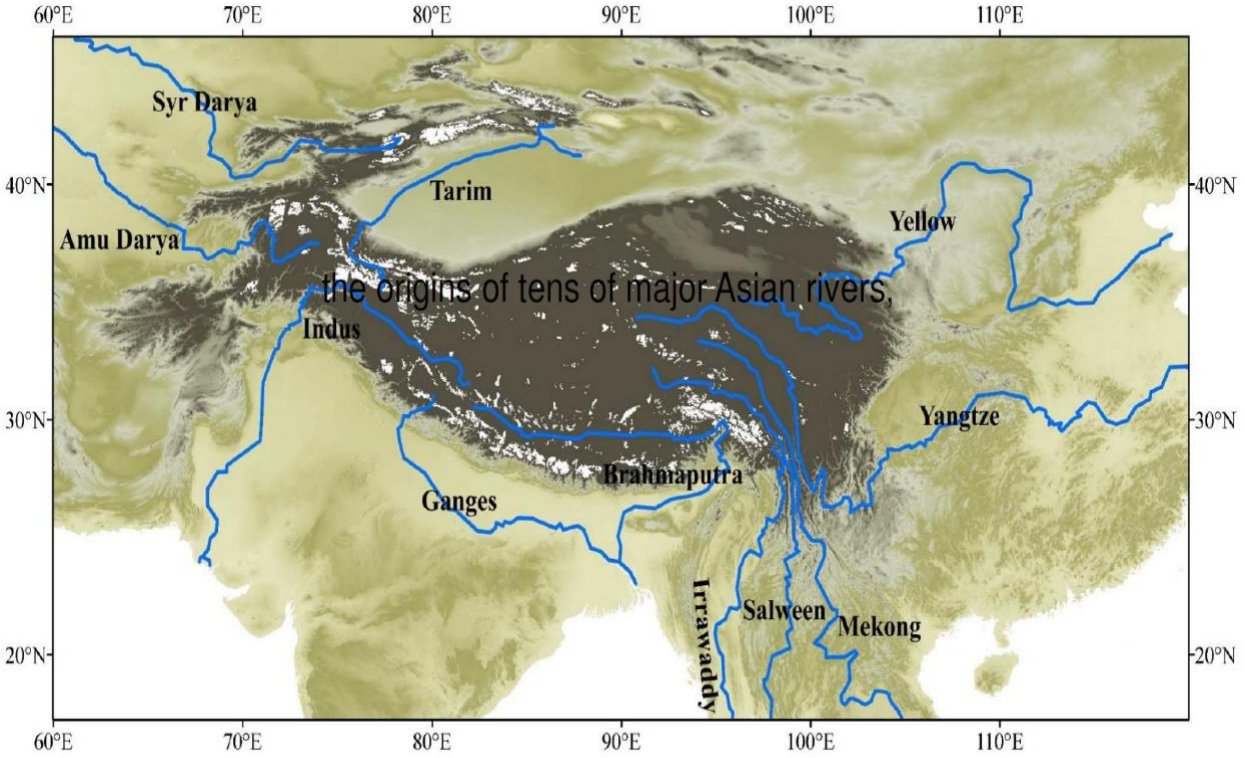
Outline

1. Background of riverine runoff and sediment flux study
2. Variations of riverine runoff on the Tibetan Plateau
3. Variations of riverine sediment flux on the Tibetan Plateau
4. Ongoing work and future perspectives

Outline

1. Background of riverine runoff and sediment flux study

The Tibetan Plateau is the headwater of more than ten large rivers in Asia, which provide precious water resources for more than 2 billion people in the region and downstream of the headwaters (Yao et al., 2015).



- The Tibetan Plateau with a total glacial area of 100,000 km^2 and a total Lake area of 50,000 km^2, is known as the “Asian water tower”.

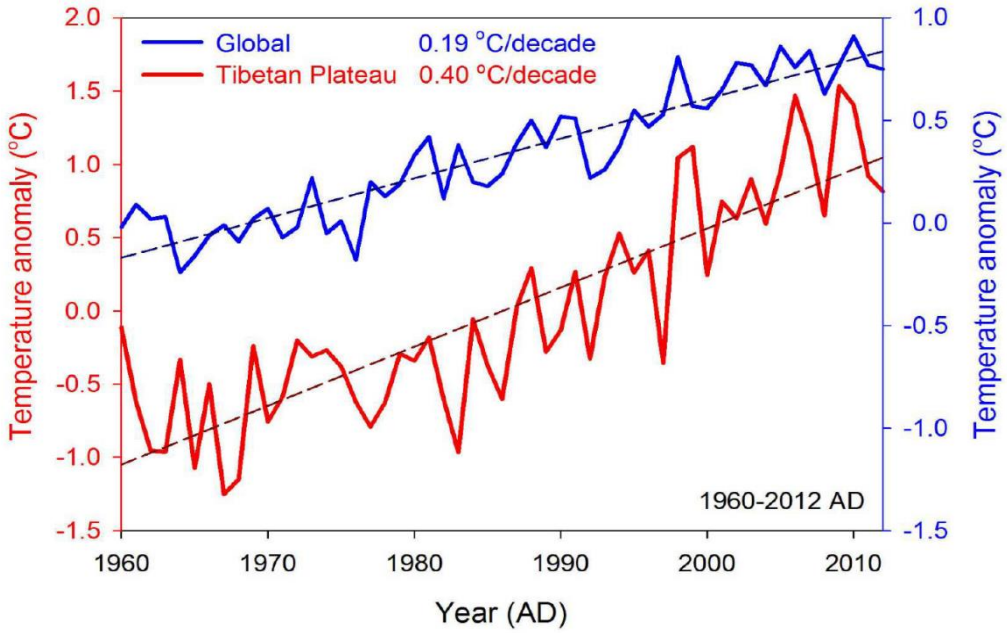
1. Background of riverine runoff and sediment flux study

Approximately one-third of the global sediment fluxes come from the large rivers originated from the Tibetan Plateau (Milliman and Meade, 1983).

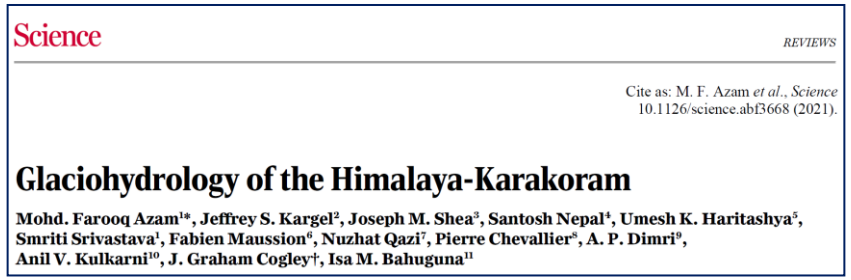
- Therefore, the rivers originated in the Tibetan Plateau are not only important sources of fresh water, but also important marine sediment transporter, influencing the downstream river geomorphology and water quality.

1. Background of riverine runoff and sediment flux study

During the last 60 years, warming rate in the Tibetan Plateau is almost twice as large as the global average. Runoff and sediment flux are important indicators of land surface processes under the influence of climate change.



Chen and Yao et al., Chin Sci Bull, 2015



Science REVIEWS

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Glaciohydrology of the Himalaya-Karakoram

Mohd. Farooq Azam[1*], Jeffrey S. Kargel[2], Joseph M. Shea[3], Santosh Nepal[4], Umesh K. Haritashya[5], Smriti Srivastava[1], Fabien Maussion[6], Nuzhat Qazi[7], Pierre Chevallier[8], A. P. Dimri[9], Anil V. Kulkarni[10], J. Graham Cogley†, Isa M. Bahuguna[11]

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The impact of glaciers on mountain erosion

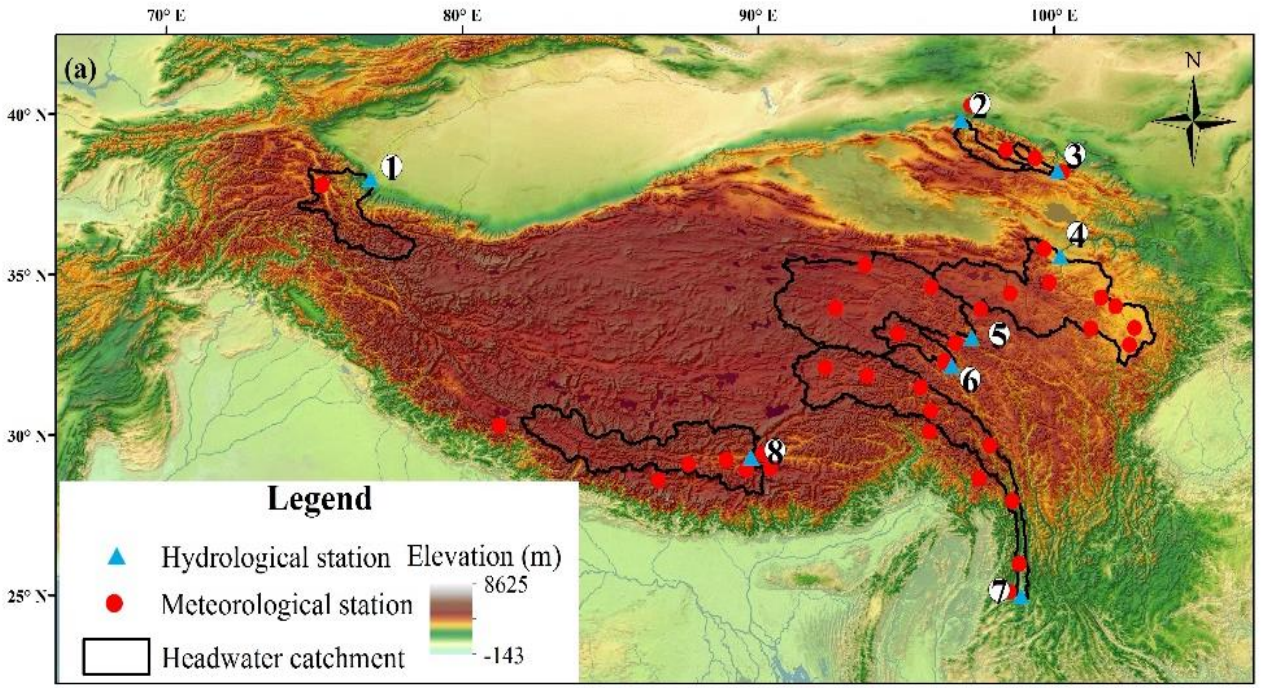
Frédéric Herman ✉, Fien De Doncker, Ian Delaney, Günther Prasicek & Michèle Koppes

Outline

1. Background of riverine runoff and sediment flux study
2. Variations of riverine runoff on the Tibetan Plateau
3. Variations of riverine sediment flux on the Tibetan Plateau
4. Ongoing work and future perspectives

2. Variations of riverine runoff on the Tibetan Plateau

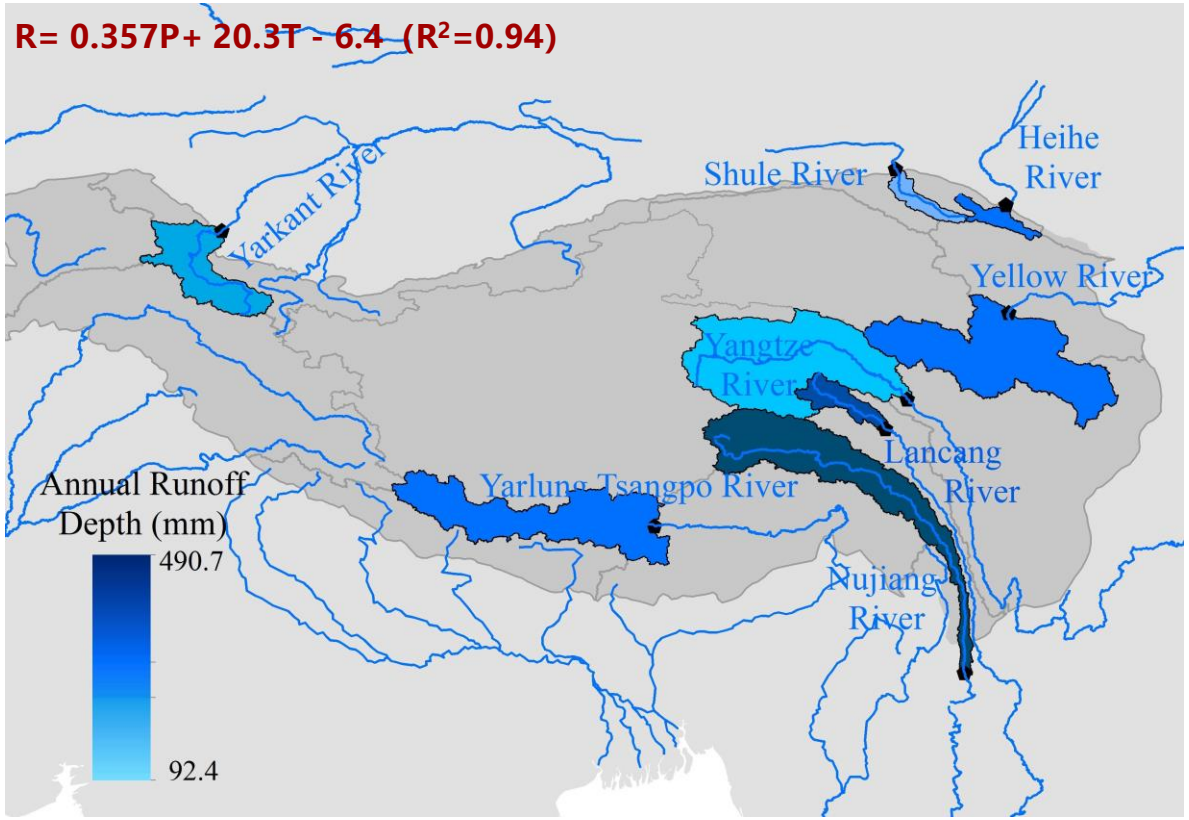
Headwater basins of eight major rivers with long-term observation in the Tibetan Plateau were selected to study riverine runoff and sediment flux variation..



Headwater catchment	Hydrological station
① Yarkant River	Kaqun
② Shule River	Changmapu
③ Heihe River	Zhamashike
④ Yellow River	Tangnaihai
⑤ Yangtze River	Zhimenda
⑥ Lancang River	Xiangda
⑦ Nujiang River	Daojieba
⑧ Yarlung Tsangpo River	Nugesha

2. Variations of riverine runoff on the Tibetan Plateau

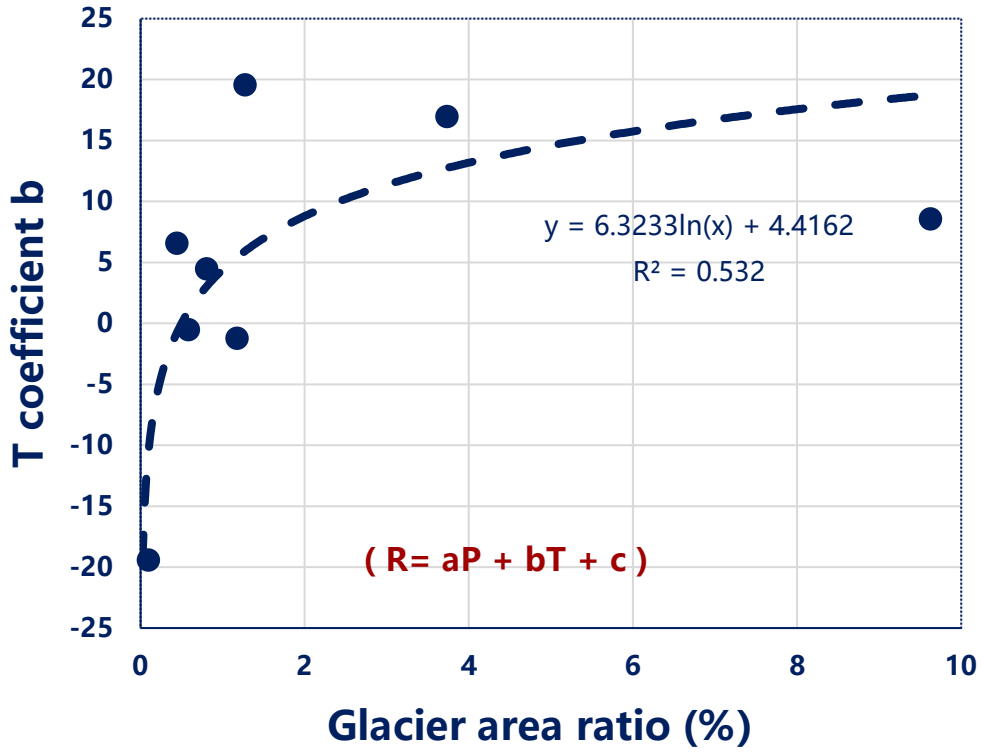
Overall, multi-year average runoff depth of headwater basins is higher in Southeast and lower in Northwest of the Tibetan Plateau.



- Precipitation is the most important factor of the average runoff depth, followed by air temperature as the second important factor.
- The runoff depth is positively related to the temperature, which indicates that the melt water supplement increase exceeds the evaporation loss increase caused by warming over the Tibetan Plateau as a whole.

2. Variations of riverine runoff on the Tibetan Plateau

The relationship between annual runoff depth and annual mean air temperature varies among the headwater basins according to the glacier area ratio.

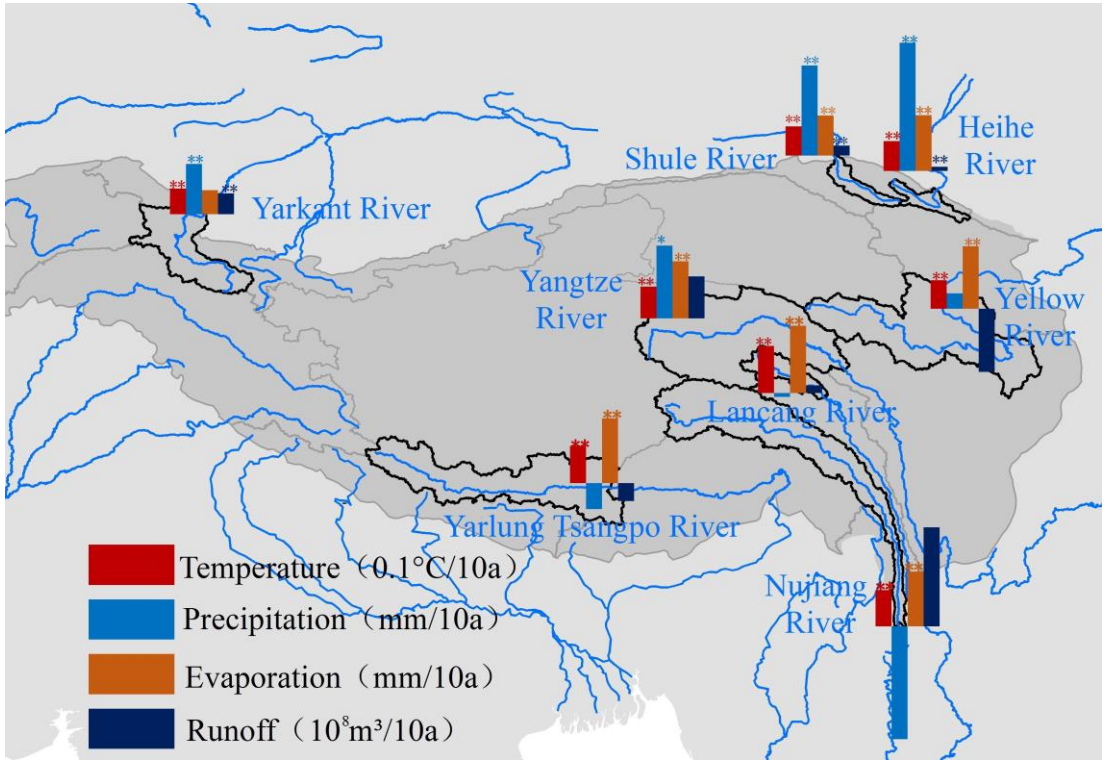


- For basins with larger glacier ratio, the temperature coefficient is positive, indicating that the effect of melt water supply caused by warming is stronger, thus the annual runoff is positively correlated with the annual mean air temperature in the basins.
- For basins with smaller glacier ratio, the temperature coefficient is negative, showing that the evaporation loss caused by warming is stronger, and the annual runoff is negatively correlated with the annual temperature.

Fan Zhang, Chen Zeng*, Guanxing Li Wang Wang, Xiaonan Shi. Runoff and sediment yield in relation to precipitation, temperature and glaciers on the Tibetan Plateau. International Soil and Water Conservation Research. 2022, 10:197-207.2022

2. Variations of riverine runoff on the Tibetan Plateau

During the last 60 years, the temperature of the eight headwater basins all showed significant increasing trends, while the precipitation and runoff showed varied trends in different basins.



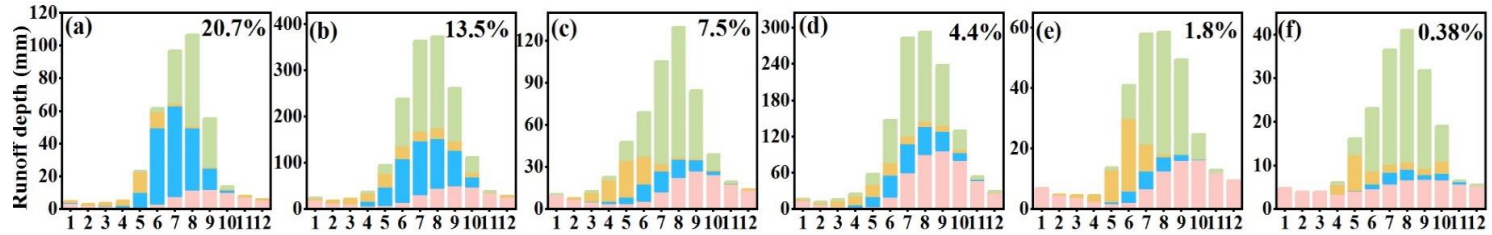
- Under warming background, the evapotranspiration in the eight headwater basins all increased significantly;
- Precipitation increased in the northern basins and decreased in the southern basins;
- The runoff in most headwater basins increased.

Zhang et al., 2019

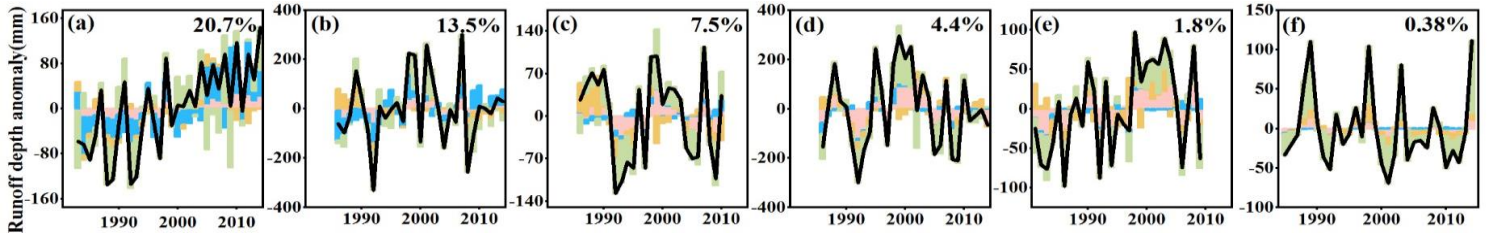
2. Variations of riverine runoff on the Tibetan Plateau

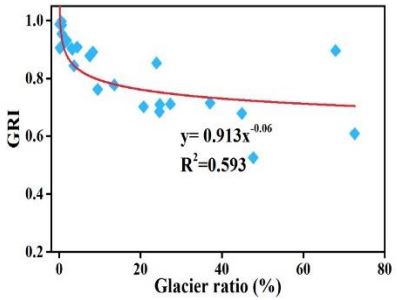
Runoff modeling in catchments with different glacier area ratios (GARs) indicated that when GAR decreases from 20% to <1%, contribution of meltwater reduces from 60% to ~20%.

Seasonal Distribution



Changing trends





- Hydrological regulation function of glaciers would decrease along with warming induced glacier retreat.

- Peak of glacier and snow melt runoff shifted from summer to spring;
- Dominating factor of runoff changing trend switched from increasing glacier melt under warming condition to precipitation changing trends;

Li Wang, Fan Zhang*, Chen Zeng, Wenjie Zhang. Variation of hydro-climatic extremes in headwater regions of Hei River basin under climate change, Journal of Hydrology: Regional Studies, 2023, 50:101561

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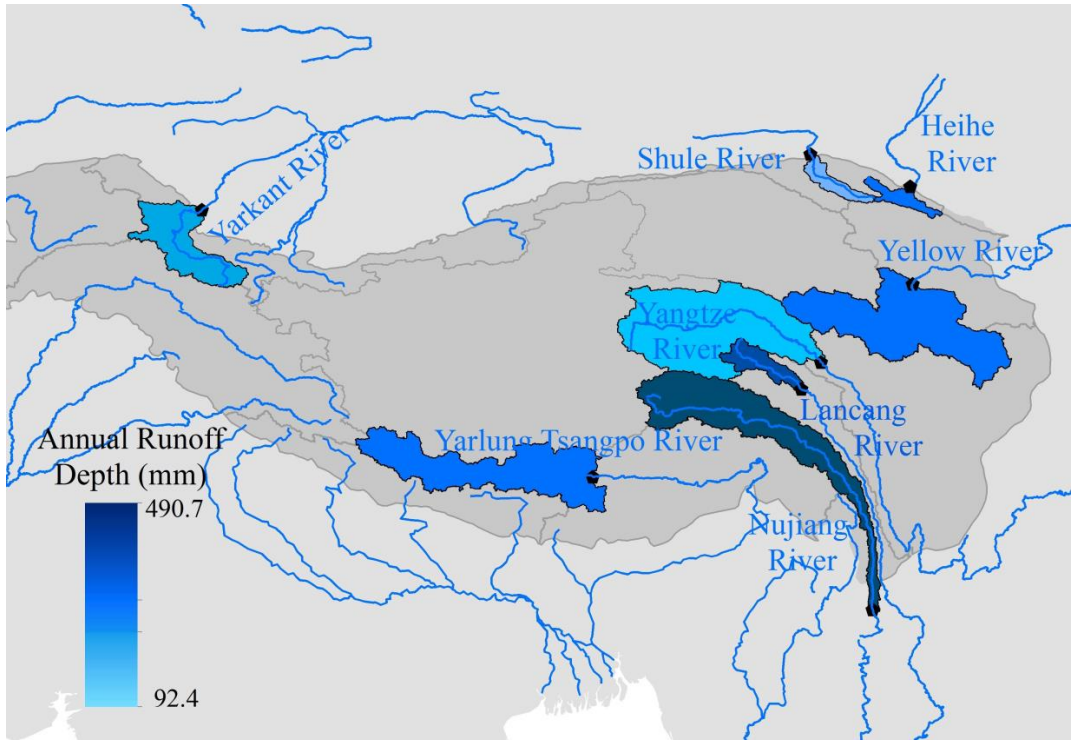
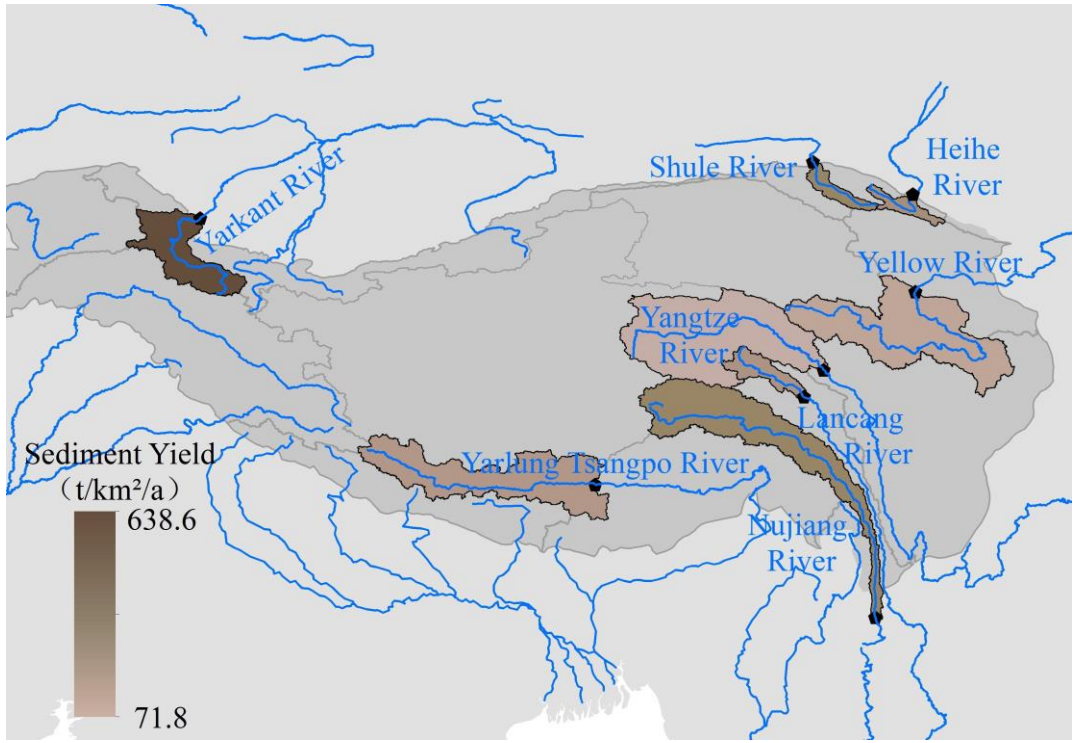
3. Variations of riverine sediment flux on the Tibetan Plateau

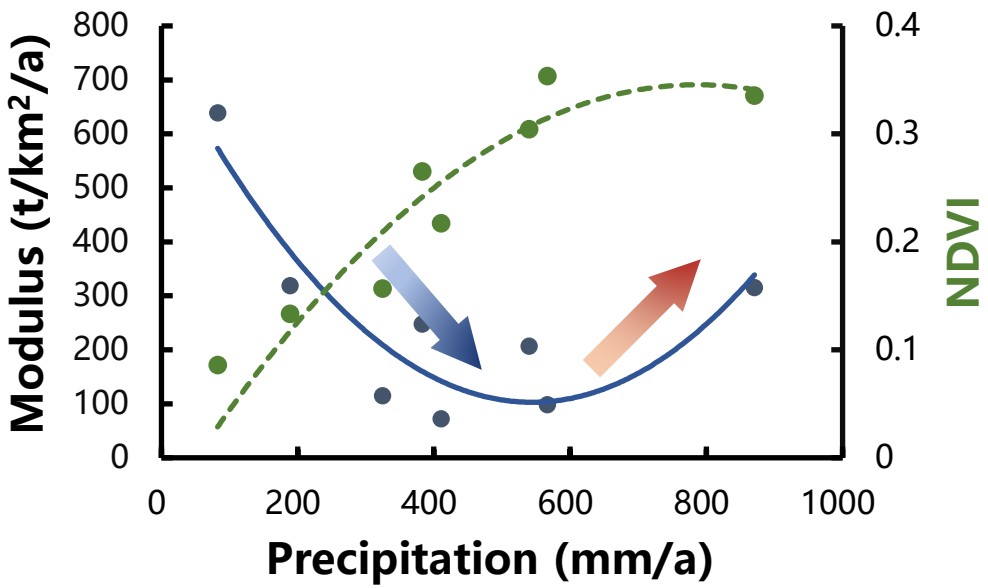
Compared to the runoff depth, the multi-year average sediment transport modulus of the eight headwater basins does not show obvious spatial pattern.





3. Variations of riverine sediment flux on the Tibetan Plateau

Stepwise multi-variable regression analysis indicates that precipitation is the most important factor of the multi-year average sediment transport modulus, followed by glacier area ratio.



$S=0.000609P^2-0.470P+48.5A_g+202.53$

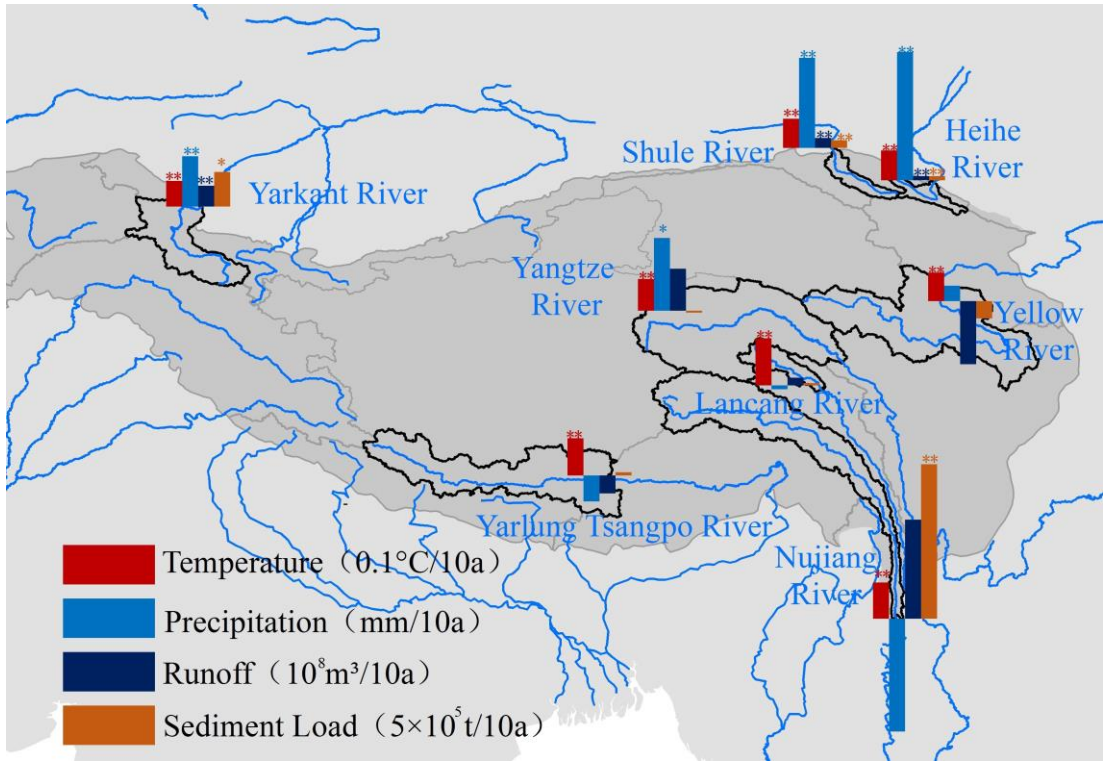
$(R^2=0.89)$

- In arid and semi-arid areas with less precipitation, the sediment transport modulus decreases with precipitation, as vegetation protection increases with NDVI.
- While in the semi humid area with larger precipitation, the sediment transport modulus increases with precipitation, as NDVI keeps stable and dominating factor changing to rainfall erosion power.
- The sediment transport modulus is positively related to the glacier area ratio, indicating high erosion intensity in glaciated area.

Fan Zhang, Chen Zeng*, Guanxing Li Wang Wang, Xiaonan Shi. Runoff and sediment yield in relation to precipitation, temperature and glaciers on the Tibetan Plateau. International Soil and Water Conservation Research. 2022, 10:197-207.2022

3. Variations of riverine sediment flux on the Tibetan Plateau

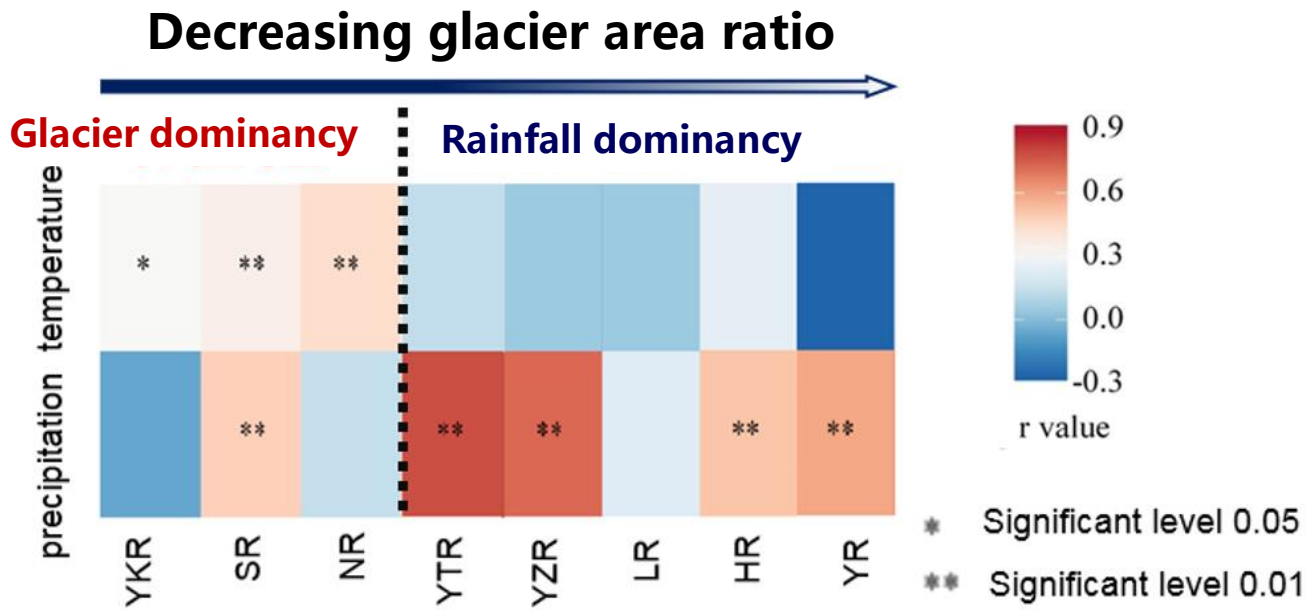
During the last 60 years, the sediment flux in the headwater basins of the Tibetan Plateau has mostly increased.



- Changing trend of sediment flux was not exactly consistent with the changing trend of runoff in each head water basin.
- The dominating increasing/stable patterns of sediment flux in rivers of the Tibetan Plateau without severe anthropogenic disturbances is quite different from the decreasing/stable patterns of large rivers of the world.

3. Variations of riverine sediment flux on the Tibetan Plateau

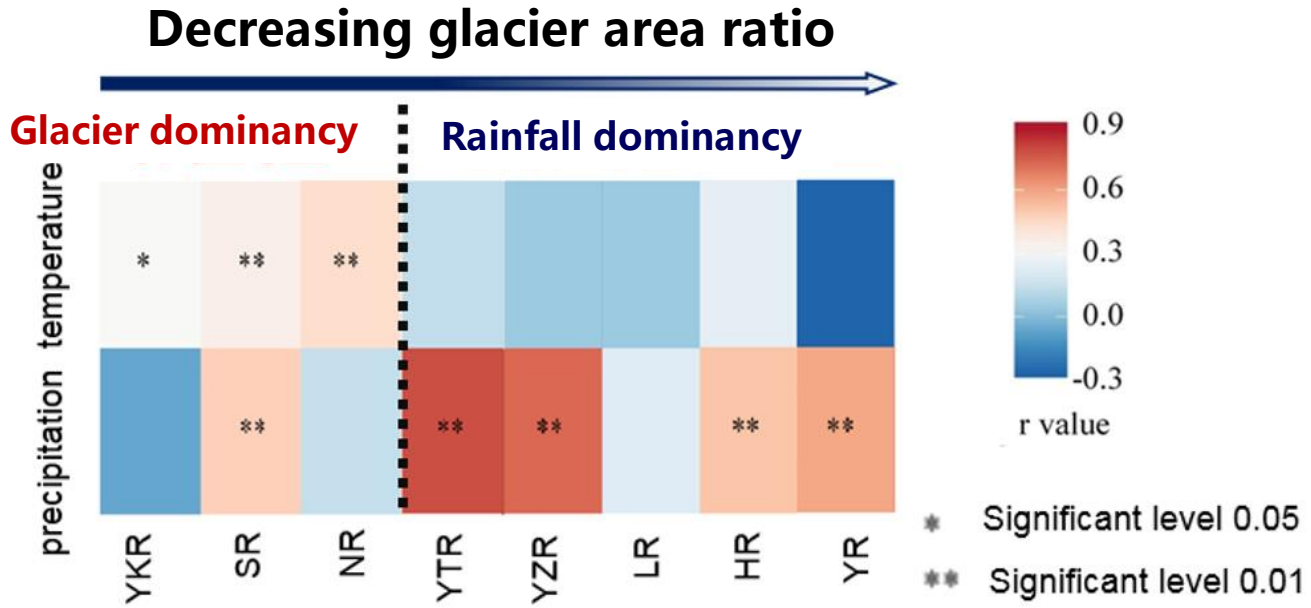
Spearman's test showed that the correlations between sediment flux and temperature/precipitation were different. The basins can be separated into two groups.



- The three headwater basins with the largest glacier area ratios are of glacier dominancy, with sediment flux positively correlated with air temperature, and the increase of ice and snow melt water lead to the significant increase of sediment flux.

3. Variations of riverine sediment flux on the Tibetan Plateau

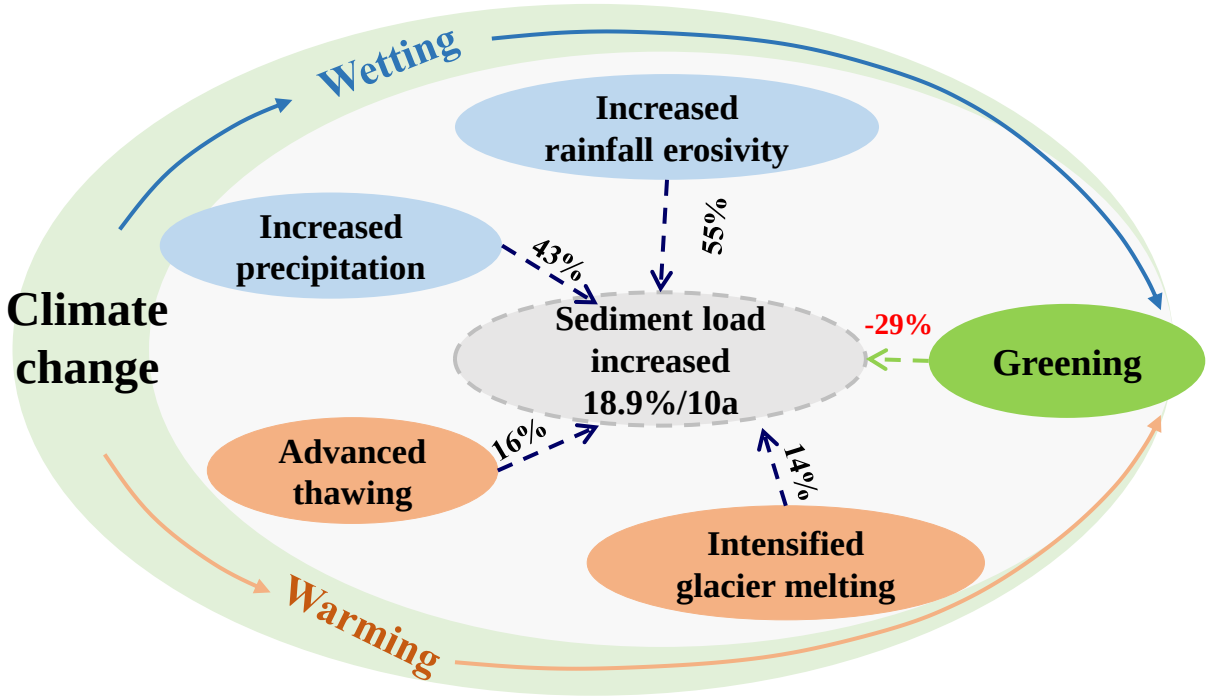
Spearman's test showed that the correlations between sediment flux and temperature/precipitation were different. The basins can be separated into two groups.



- The other five headwater basins with relatively smaller glacier area ratios are of precipitation dominancy, with sediment flux mainly affected by rainfall erosion, and showed varied changing trends depending on the precipitation changes.

3. Sediment flux changes in the Tuotuo River

Research on the headwater of the Brahmaputra River with GAR of 1.17%, revealed that from 1972 to 2008, temperature, precipitation, glacier runoff, and sediment flux all showed significant increasing trends, with total runoff showing no significant changing trend.



- The increase in fluvial sediment flux was primarily due to increases in precipitation (98%), combined with influences from increased sediment supply due to longer thawing period (16%) and intensified glacier melting (14%).
- The increases in fluvial sediment load were partially buffered by a decrease in water yield capacity due to denser vegetation cover (−29%).

Xiaonan Shi, Fan Zhang*, Xixi Lu, et al. The response of the suspended sediment load of the headwaters of the Brahmaputra River to climate change: Quantitative attribution to the effects of hydrological, cryospheric and vegetation controls. Global and Planetary Change. 2022, 210:103753

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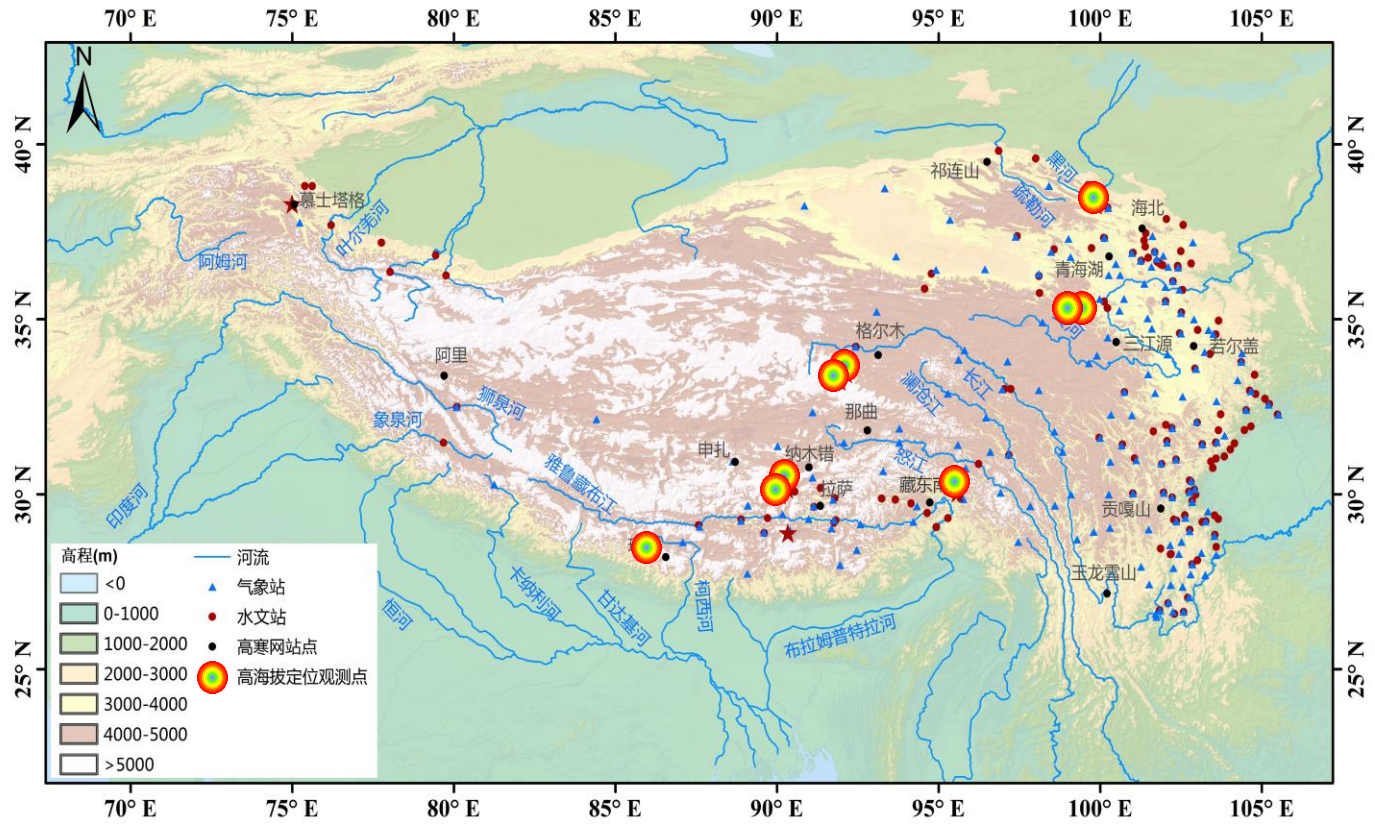
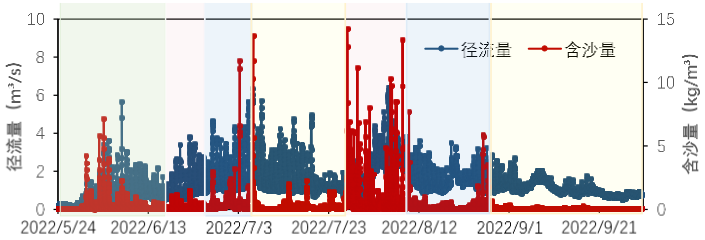
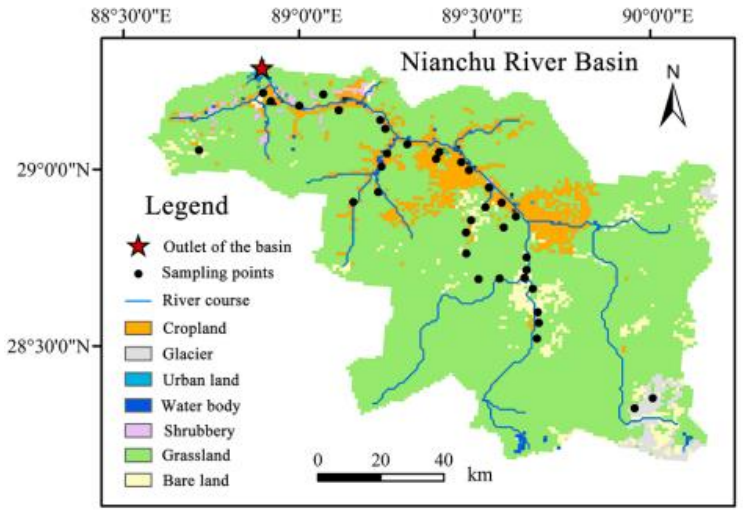
Carry out in-situ monitoring of water level and Turbidity, to obtain continuous data of runoff and sediment flux at high altitude river/stream cross sections.

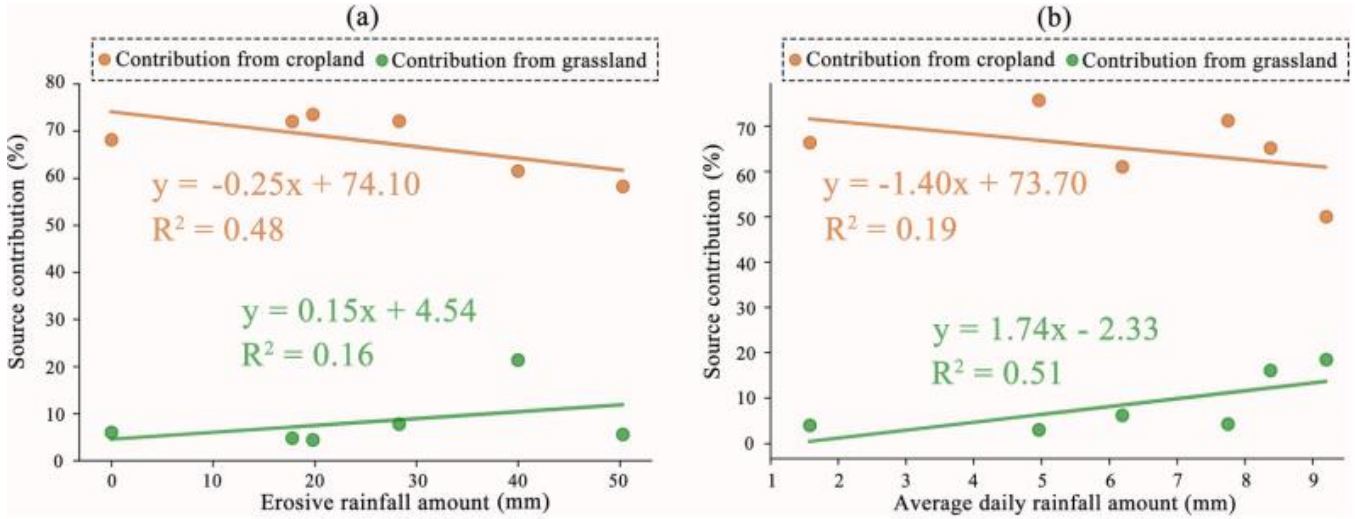




4. Ongoing work and future perspectives

Perform sediment source fingerprinting study to obtain quantitative information on suspended sediment sources to understand soil erosion and sediment transport processes.



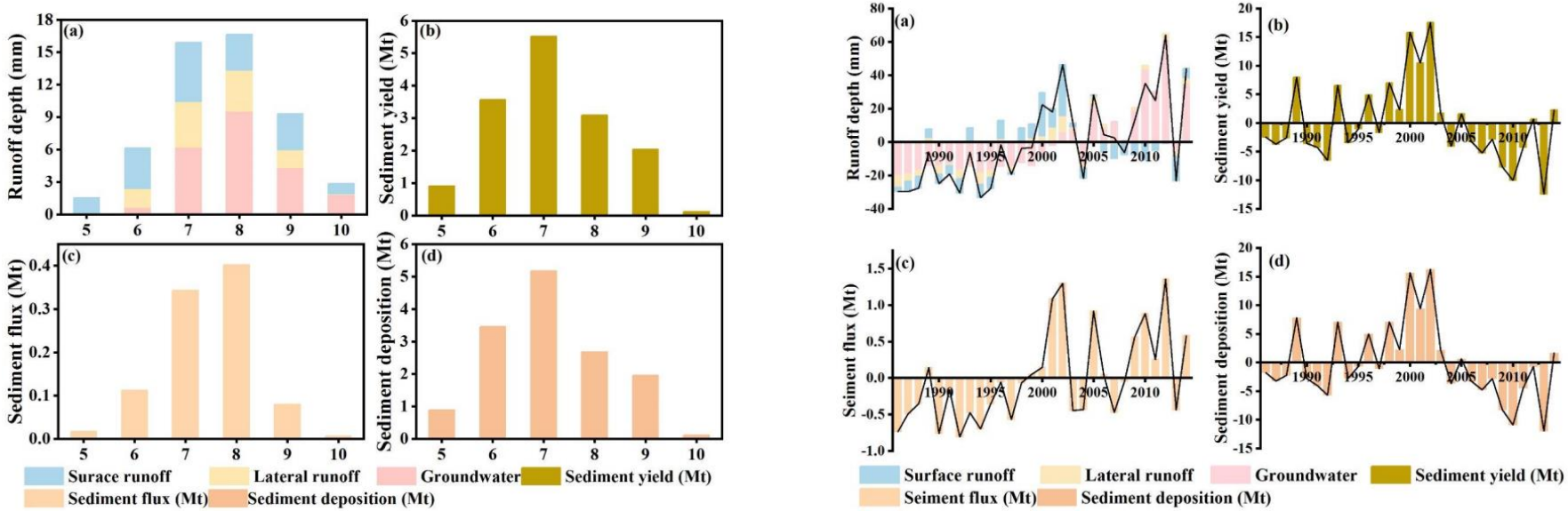


- Cropland close to the river channel with an area ratio of only 8.6% consistently contributed more than 50% of the suspended sediment during the wet period.
- The relative contributions from the cropland and grassland showed a negative and positive linear relationship with rainfall intensity, respectively, indicating increased sediment connectivity from grasslands to river channels under rainfall conditions.

Yang Zhao, Fan Zhang*, Chen Zeng, Xiaonan Shi, Jinyu Kong, Shenqi Xie. Quantifying the sources of suspended sediments in the Nianchu River Basin, southern Tibetan Plateau: evaluation and application of a semiempirical fingerprinting framework. Journal of Hydrology. 2024, 630, 130711

4. Ongoing work and future perspectives

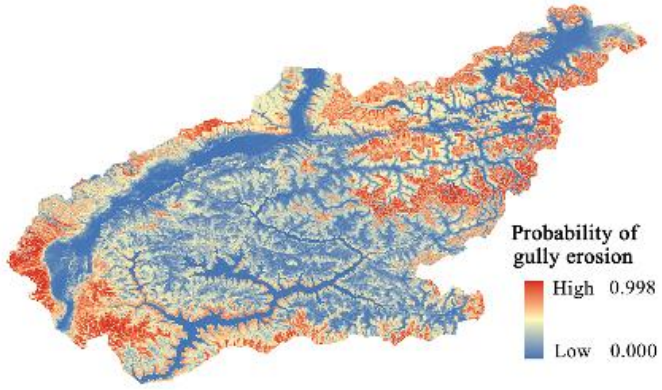
Carry out soil erosion and sediment transport modeling to evaluate the impact of temperature, precipitation and land use land cover changes on sediment flux changes.

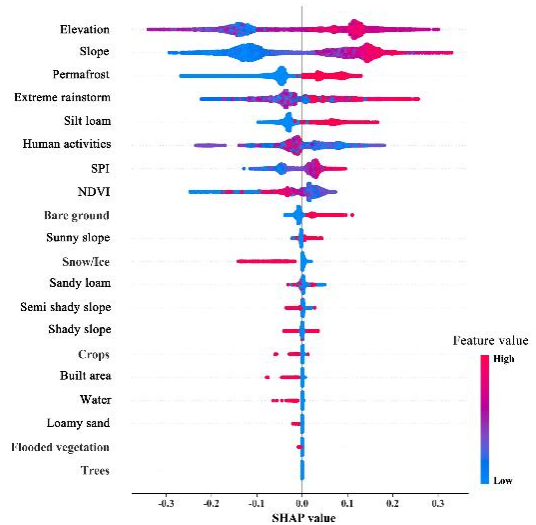


- Simulation of runoff and sediment transport in headwater of Yangtze River in the last 30 years indicated that surface runoff decreased with permafrost degradation, along with NDVI increase, resulting in soil erosion and sediment deposition reduction. While the total runoff increase caused outlet sediment flux increase.

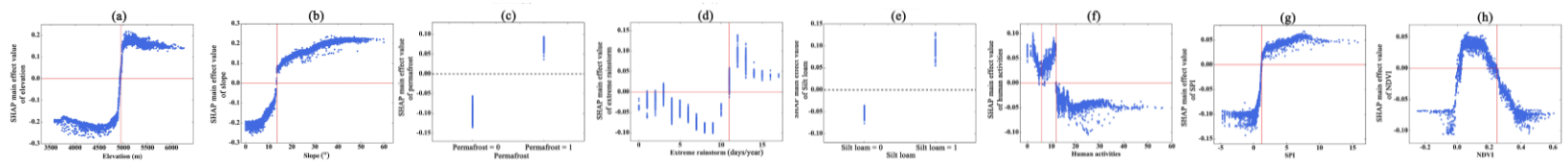
4. Ongoing work and future perspectives

Gully erosion rate need to be investigated based on in-situ observation and gully erosion module should be added to distributed soil erosion and sediment transport model.





- Based on field investigations and interpretation using high-resolution satellite remote sensing images, the Random Forest (RF) algorithm was applied to evaluate gully erosion **susceptibility** of the Lhasa River basin.
- Areas with elevation > 4950 m, slope > 13.5°, extreme rainstorms > 11 days/year, with silt loam topsoil, presence of **permafrost**, stream power index > 1.2, and normalized difference vegetation index (NDVI) < 0.25 are suspected to high gully erosion probability.



Wenjie Zhang, Yang Zhao*, Fan Zhang*, Xiaonan Shi, Chen Zeng, Michael Maerker. Understanding the mechanism of gully erosion in the alpine region through an interpretable machine learning approach. Science of the Total Environment, 2024, 949:174949

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