Risk assessment and contribution analysis of water erosion in China from 1999 to 2018

Han Wang

Email: han.wang@mail.bnu.edu.cn

Faculty of Geographical Science

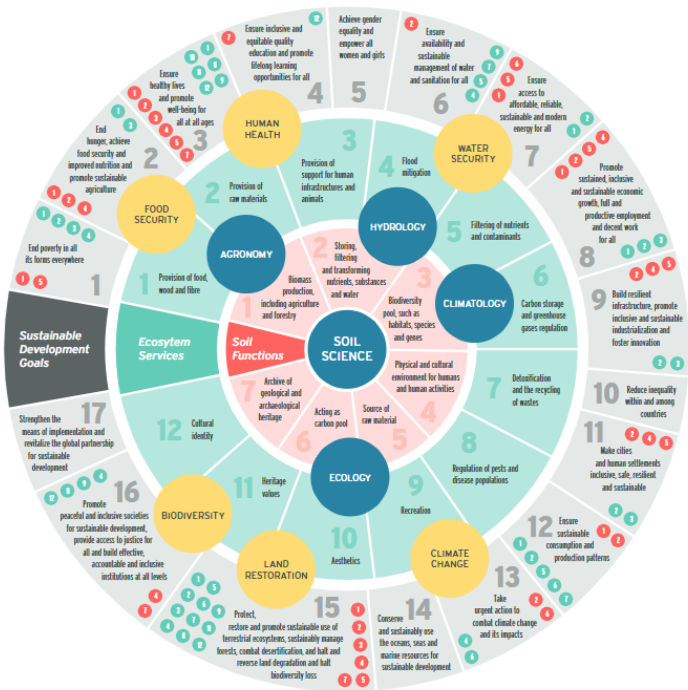
Beijing Normal University

OUTLINE

1. **Background**
2. **Data & Methods**
3. **Results and Discussion**
4. **Summary**

01 Background

- The United Nations set forth 17 Sustainable Development Goals (SDGs) (Nations, 2015), and 13 of them are related to soil (Keesstra et al., 2016).
- SDG 2 expressly mentions the significance of preserving soil quality for realizing food security, while SDG 15 appeals for a land degradation-neutral world by 2030.

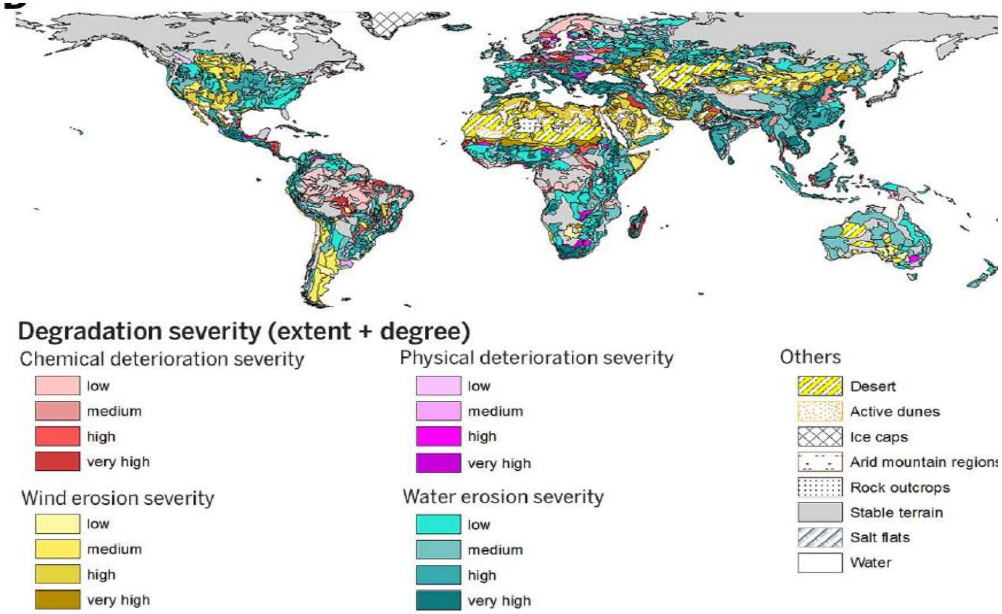


（Keesstra *et al., Soil,* 2016)

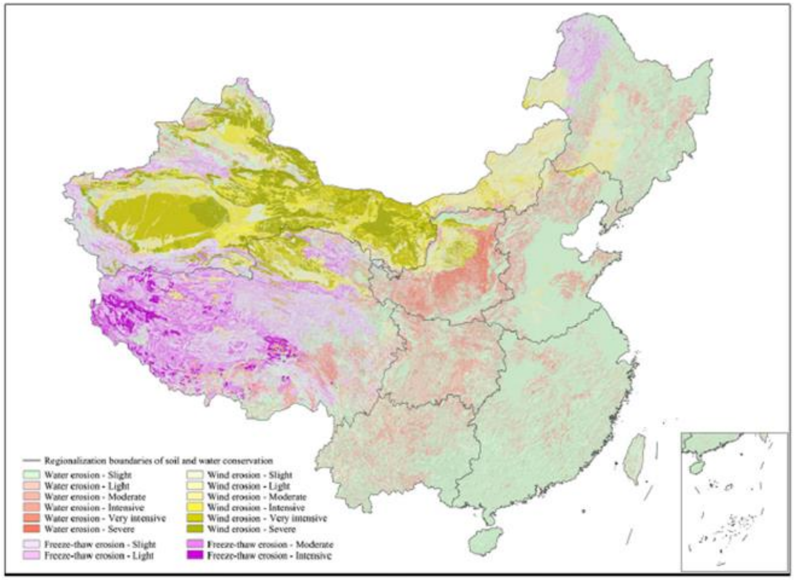
（Keesstra *et al., Soil,* 2018)

Healthy soil is vital to achieving the SDGs.

01 Background

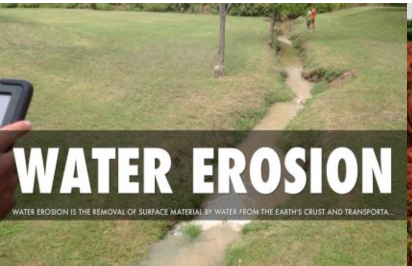


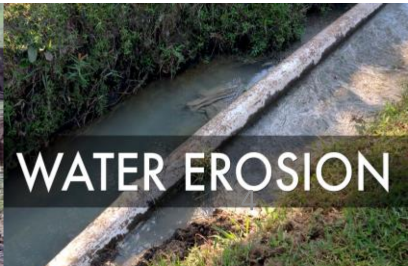
(Amundson *et al.*, *Science,* 2015)



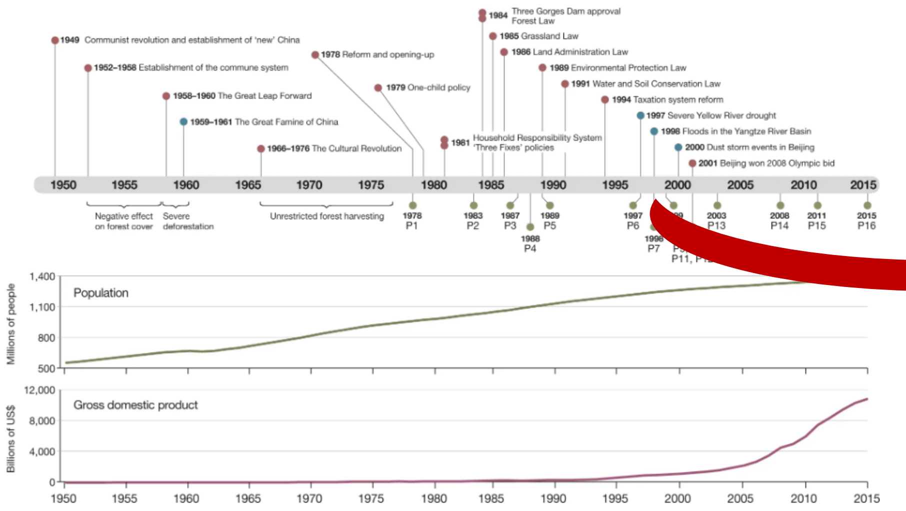
(Wang *et al.*, *Catena,* 2015)

Soil erosion by water is one of the major threats to soils, which results in not only fertility loss and land degradation, but induces a conspicuous number of off-site effects





01 Background



Chronology of key political/socio-economic/policy events (red markers), human-environmental disasters (blue markers), and the 16 major sustainability programme responses (green markers) in China from 1949 to 2015. Also included are the trajectories of population and economic development (gross domestic product or GDP).

China's response to a national land-system sustainability emergency

(Bryan et al., *Nature*, 2018)

P8 Grain for Green Program. 1999–2020. Prevent soil erosion, mitigate flooding, store carbon, and improve livelihoods by increasing forest and grassland cover on cropped hillslopes and converting cropland, barren hills and wasteland to forest.

2018 marks the 20th year of GFGP's implementation.

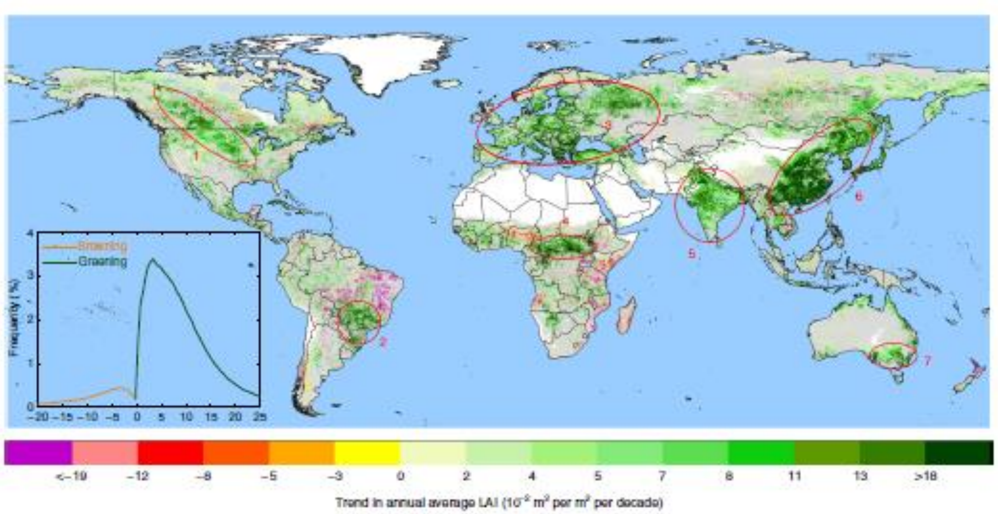
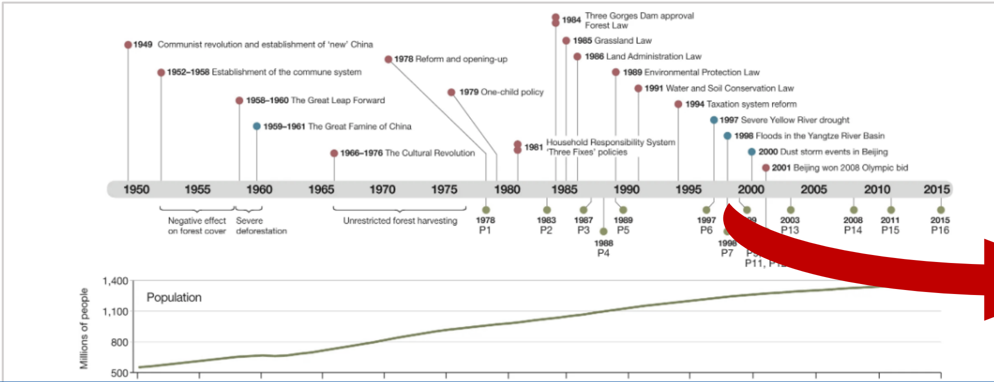


Fig. 1 | Map of trends in annual average MODIS LAI for 2000–2017. Statistically significant trends (Mann-Kendall test, $P \leq 0.1$) are colour-coded. Grey

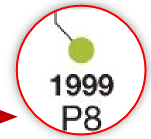
China lead in greening of the world through large-scale afforestation

(Chen et al., *Nature Sustainability*, 2019)

01 Background



2018 marks the 20th year of GFGP's implementation.



P8 Grain for Green Program. 1999–2020. Prevent soil erosion,

Have Chinese afforestation practices improved soil environmental problems in the past 20 years?

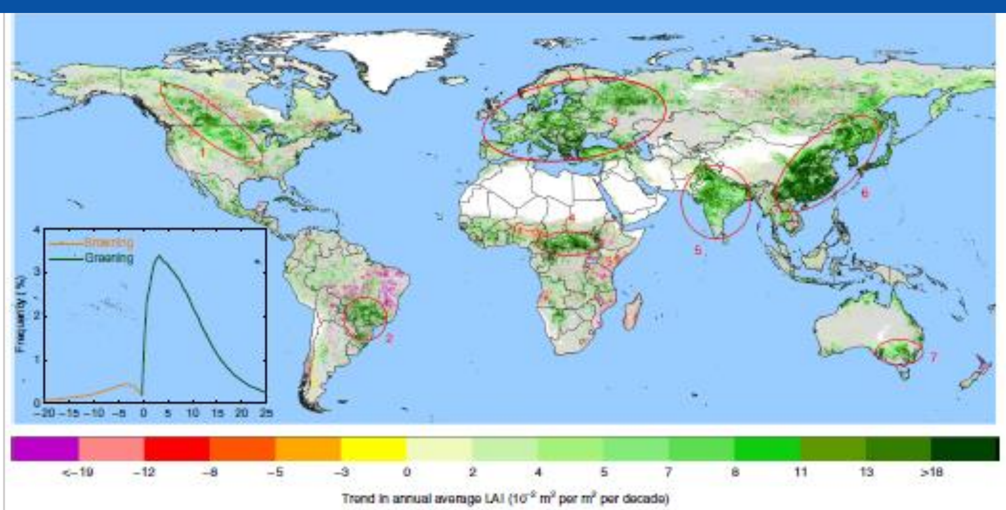
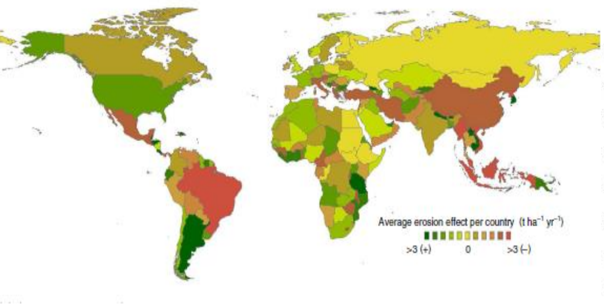


Fig. 1 | Map of trends in annual average MODIS LAI for 2000–2017. Statistically significant trends (Mann-Kendall test, P ≤ 0.1) are colour-coded. Grey

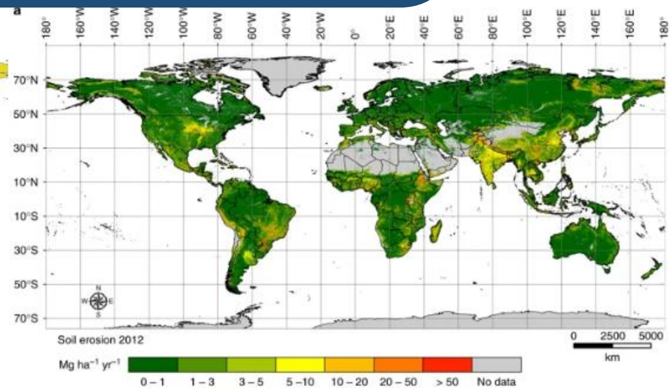
China lead in greening of the world through large-scale afforestation

(Chen et al., *Nature Sustainability*, 2019)

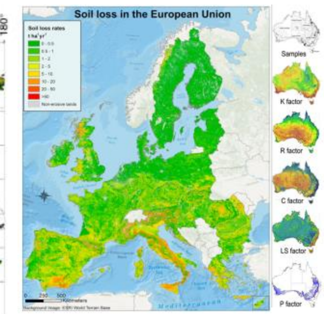
01 Background



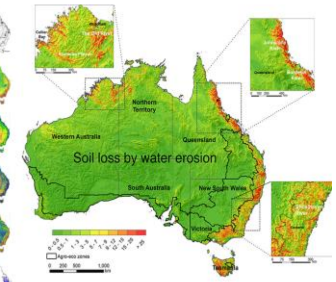
(Wuepper *et al.*, *Nature Sustainability*, 2019)



(Borrelli *et al.*, *Nature Communications*, 2017)

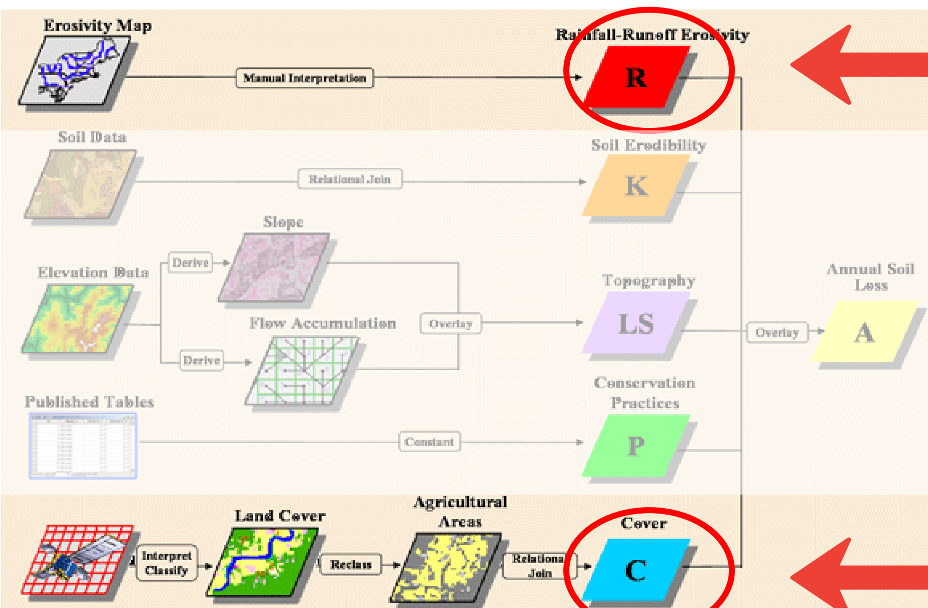


(Panagos *et al.*, *Environmental Science & Policy*, 2015)



(Teng *et al.*, *Environmental Modelling & Software*, 2016)

The Revised Universal Loss Equation (**RUSLE**) is a frequently used tool for water erosion estimation on a large scale.



(https://www.uvm.edu/rsenr/sal)

Precipitation

Vegetation

Precipitation and vegetation are interactive elements, and the two factors may offset each other in terms of soil erosion change.

01 Background

1. How has the risk of water erosion changed in China in the past 20 years, since the implementation of the GFGP?

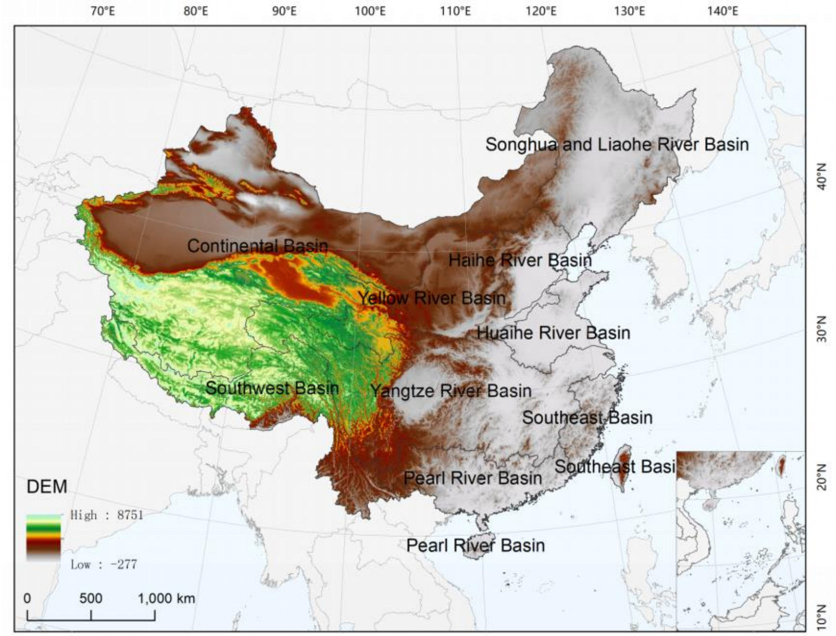
2. What did the expansion of vegetation have impacted on rainfall erosivity under the changes in water erosion?

OUTLINE

1. Background
2. Data & Methods
3. Results and Discussion
4. Summary

02 Data

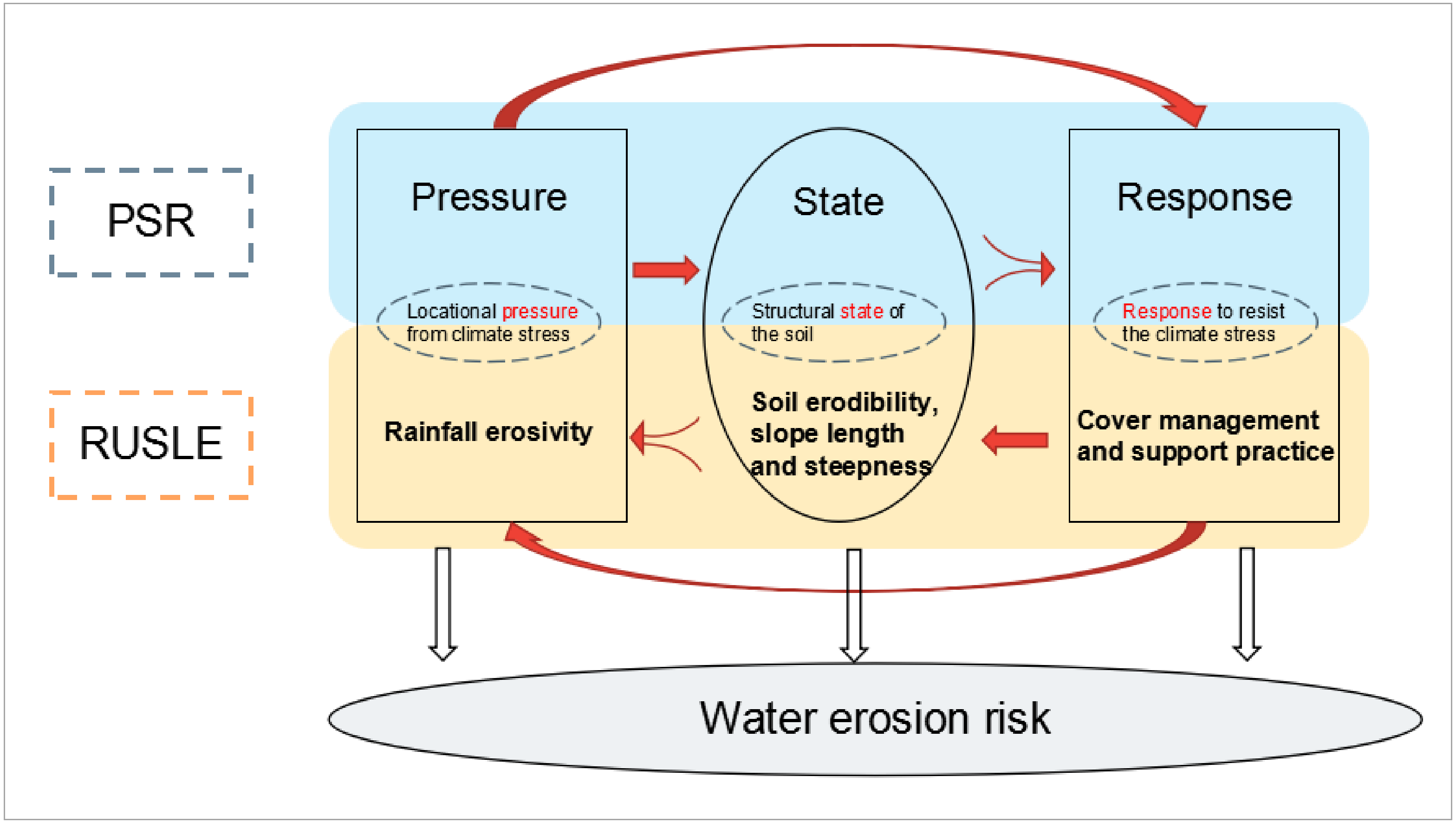
- Research period: 1999–2018
- Spatial resolution：500m



DATA	RESOLUTION	SOURCE
the Daily Rainfall Data	-	China Meteorological Data Service Center (CMDC) - Dataset of daily climate data from Chinese surface stations for global exchange (V3.0)
NDVI	500m	The MOD13A1 V6 product
Soil Properties	250m	ISRIC (International Soil Reference Information Centre): SoilGrids
DEM	90m	NASA(National Aeronautics and Space Administration): STRM（Shuttle Radar Topography Mission)

02 Methods

➢ Water erosion risk assessment framework



The indicator system of water erosion risk derived from the Revised Universal Soil Loss Equation (RUSLE) combining Pressure-State-Response (PSR).

02 Methods

Contribution of the indicators

$$\Delta VR_i = \frac{R_i \times K \times LS \times C_{i-1} - R_{i-1} \times K \times LS \times C_{i-1}}{R_{i-1} \times K \times LS \times C_{i-1}}$$

$$= \frac{(R_i - R_{i-1}) \times C_{i-1}}{R_{i-1} \times C_{i-1}}$$

$$\Delta VC_i = \frac{R_{i-1} \times (C_i - C_{i-1})}{R_{i-1} \times C_{i-1}}$$

$$R_{contr} = \frac{\Delta VR_i}{|\Delta VR_i| + |\Delta VC_i|}$$

$$C_{contr} = \frac{\Delta VC_i}{|\Delta VR_i| + |\Delta VC_i|}$$

- ΔVRi is the percent change of the water erosion risk caused by pressure R;
- ΔVCi is the percent change of the water erosion risk caused by response C;
- Rcontr and Ccontr are the pressure and response contributions to risk change, respectively.

Trend analysis

The Theil-Sen procedure with a Mann-Kendall significance test

$$\text{Slope} = \text{Median}\left(\frac{x_j - x_i}{t_j - t_i}\right)$$

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \text{sign}(x_i - x_j)$$

$$\text{sign}(X_i - X_j) = \begin{cases} 1 & \text{if} \quad x_i - x_j < 0 \\ 0 & \text{if} \quad x_i - x_j = 0 \\ -1 & \text{if} \quad x_i - x_j > 0 \end{cases}$$

$$\text{Var}(S) = \frac{n(n-1)(2n+5)}{18} = \sigma^2$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{for} \quad S > 0 \\ 0 & \text{for} \quad S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{for} \quad S < 0 \end{cases}$$

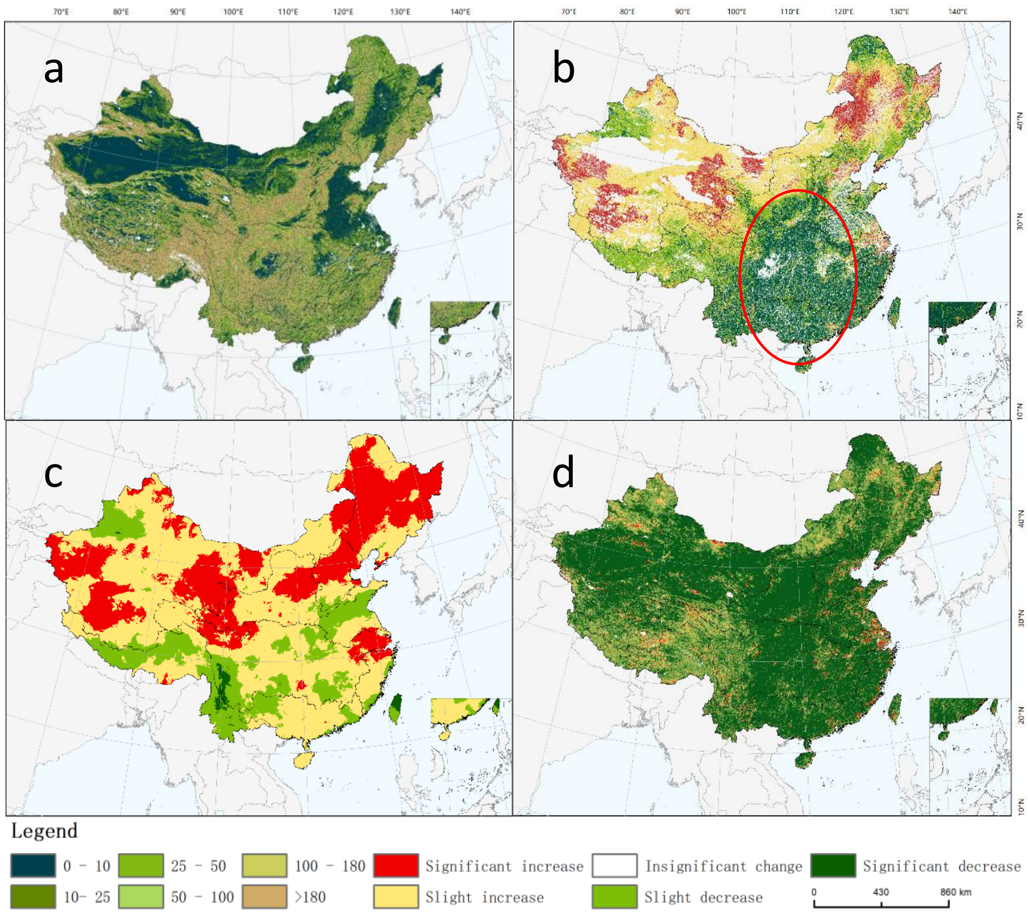
- A slope >0 indicates an increase trend, a slope <0 indicates a decrease;
- In terms of time series variables (x_1, x_2, ...,x_n), n represents the length of the time series;
- σ is the standard deviation;
- | Z |> 1.64 indicates a significant trend.

OUTLINE

1. Background
2. Data & Methods
3. Results and Discussion
4. Summary

03 Results and Discussion

The trends in pressure, response, and risk of water erosion



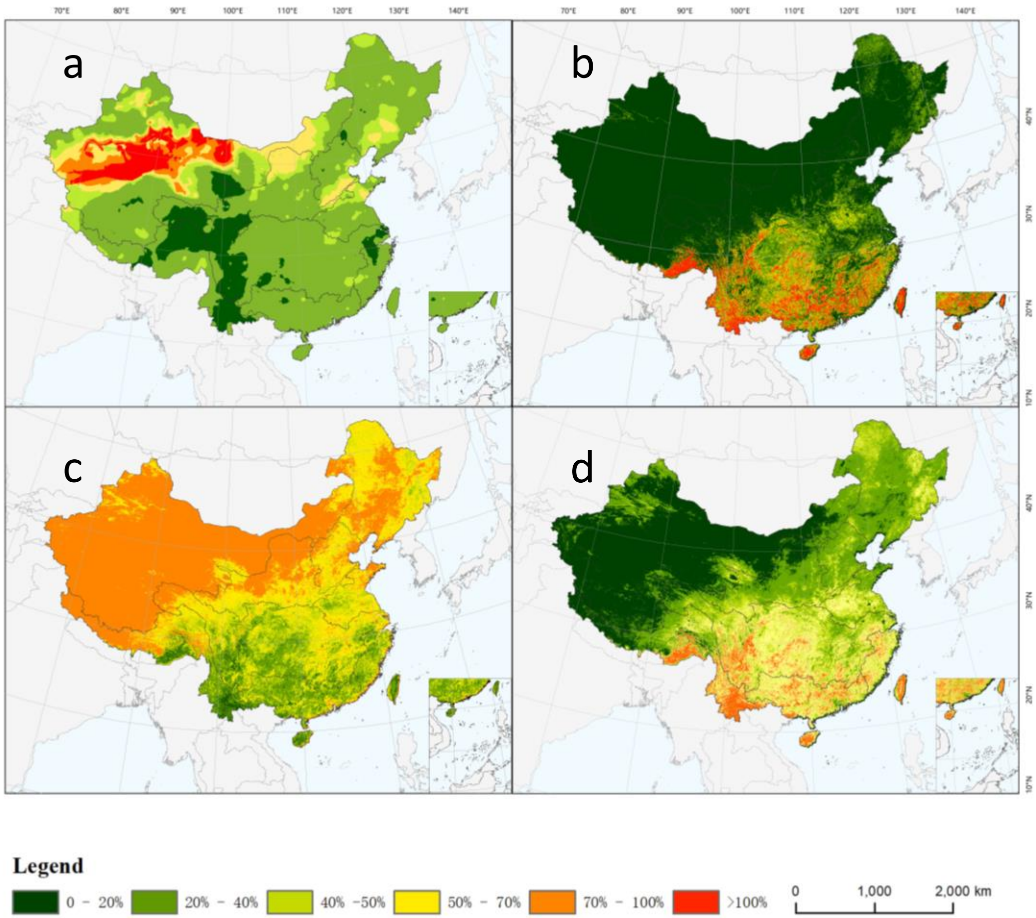
(a) Mean annual risk; (b) trend in risk; (c) trend in pressure; (d) trend in response.

- Pixels with a risk value of greater than 100 are prominently clustered in Yellow River Basin, Yangtze River Basin and Southwest Basin.
- The area with decreasing risk accounted for 52% of changed area.
- The vegetation greening in southern China likely offsets the increasing rainfall stress, resulting in a decreasing trend of risk.

A preliminary inference could be that the vegetation greening can partly offset increasing rainfall stress nationally.

03 Results and Discussion

The pressure and response contributions



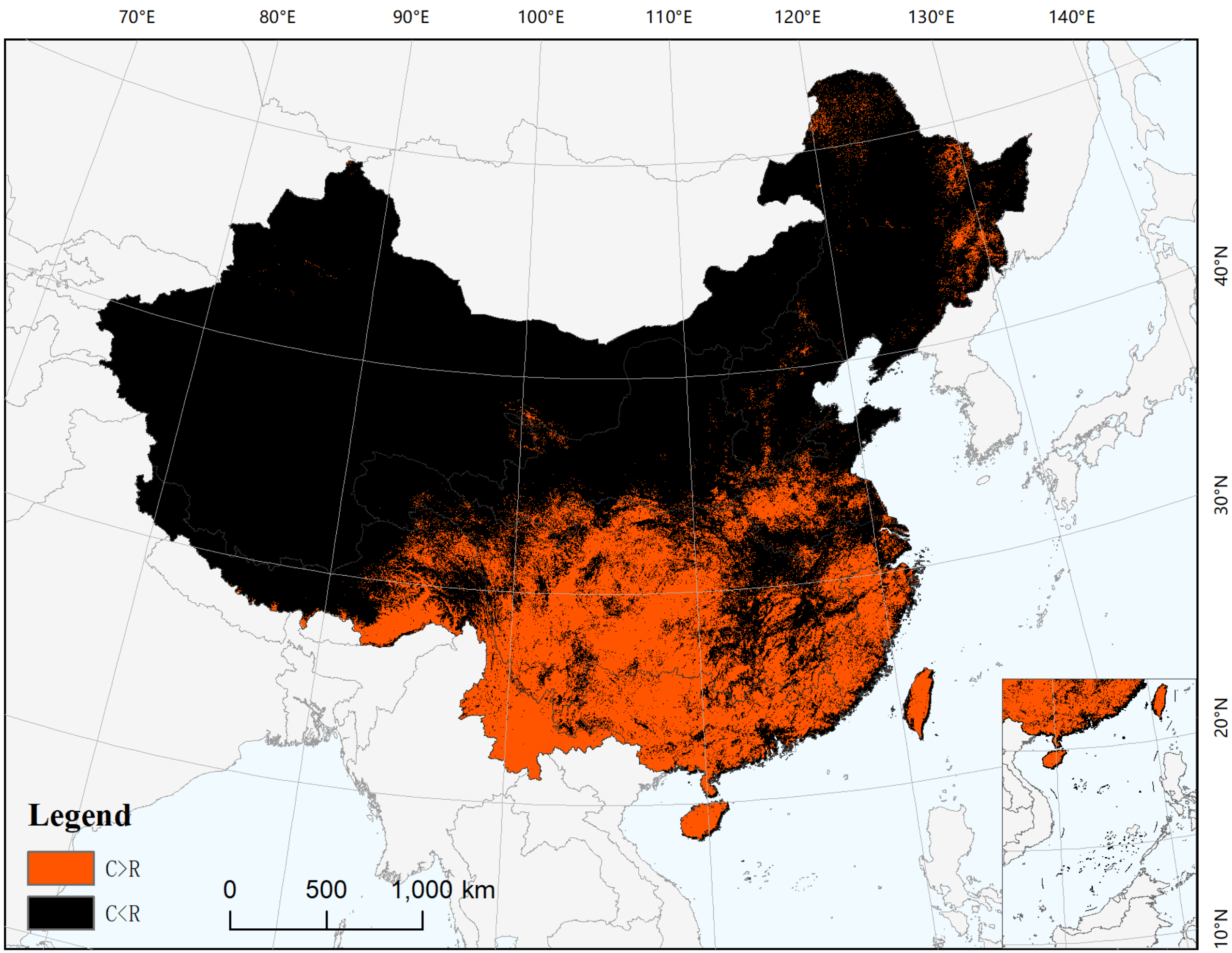
(a) Percent change induced by pressure; (b) percent change induced by response; (c) pressure contribution; (d) response contribution.

- Generally, the pressure indicator has changed more dramatically than response indicator.
- The absolute contribution of pressure is typically greater than 50%, while the value of response is greater than 50% in only areas south of the Yellow River Basin. Therefore, the contribution of response is more than that of pressure in the above-mentioned regions.

The change of pressure indicator is the dominant driver to risk changes over the two decades.

03 Results and Discussion

The spatial heterogeneity in contribution factors

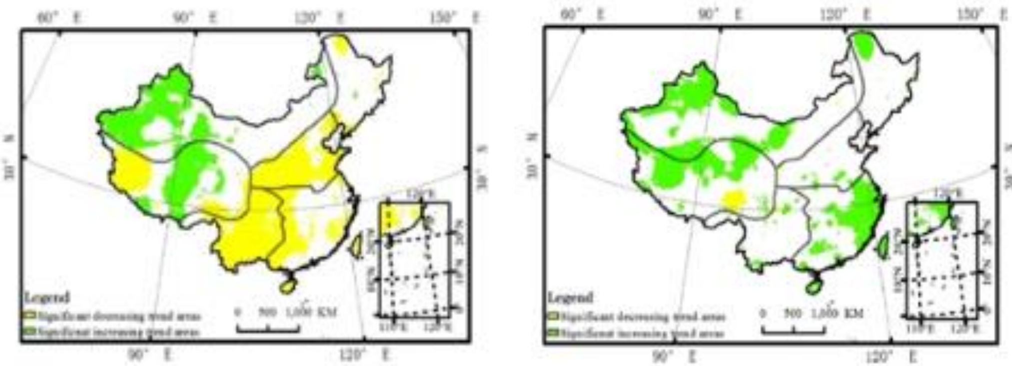


The contribution of C is more than that of R in the regions south of the Yellow River Basin while the greater contribution of R observed in the regions north of the Yellow River Basin.

03 Results and Discussion

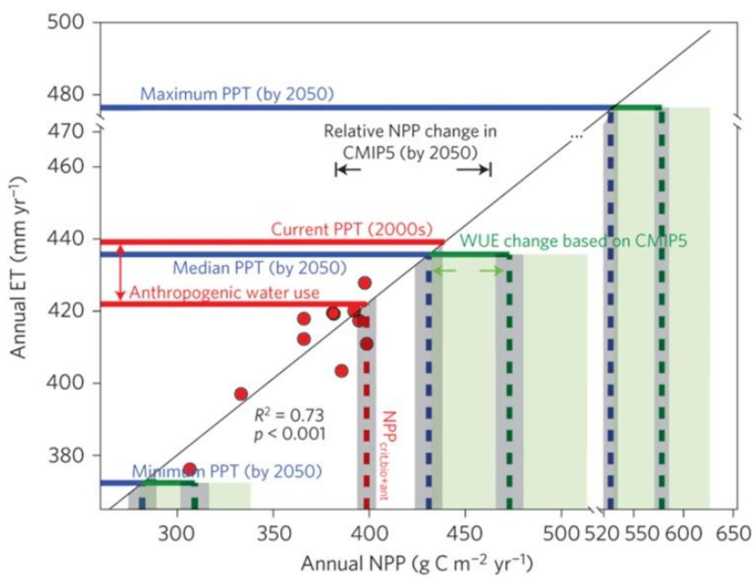
The spatial heterogeneity in contribution factors

- ✓ Water erosion in northern China is more sensitive to precipitation changes because vegetation coverage is low, the rainfall with high intensity falling in a short duration. In north region, the frequency and intensity of precipitation increased in recent decades, and the upward trend of extreme precipitation was significant.
- ✓ Southern China has an extensive vegetation coverage with high productivity, which was highly resistant to changes in rainfall pressure.



Precipitation frequency   Precipitation intensity

(Guo *et al.*, *Scientific Reports*, 2020)

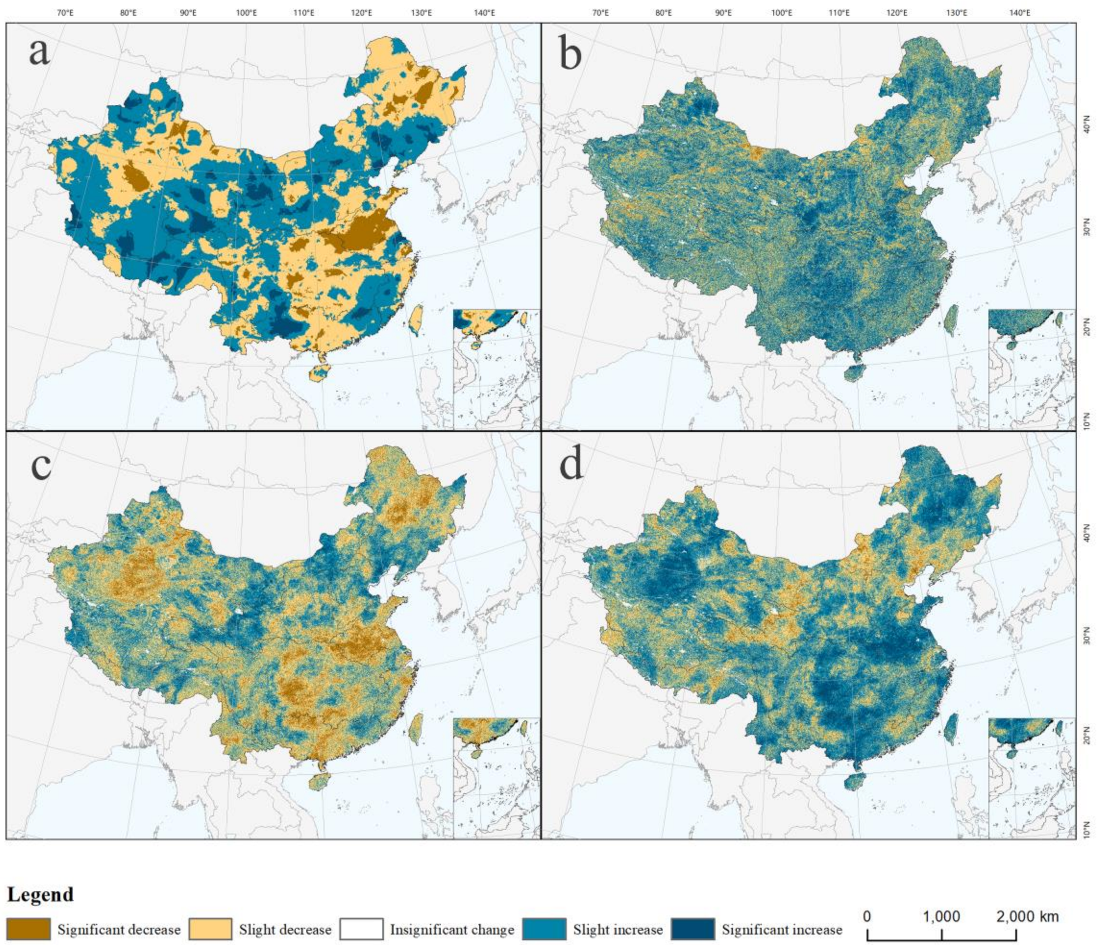


(Feng *et al.*, *Nature Climate Change*, 2016)

- ✓ The ecological benefits of vegetation restoration varied geographically
- ✓ The water scarcity in arid and semi-arid regions of China limits the feasibility and ecological benefits of afforestation.
- ✓ Afforestation in the Loess Plateau is reaching the limits of sustainable water use and thus threatening local food security.

03 结果与讨论

Evolution of the pressure and response contributions

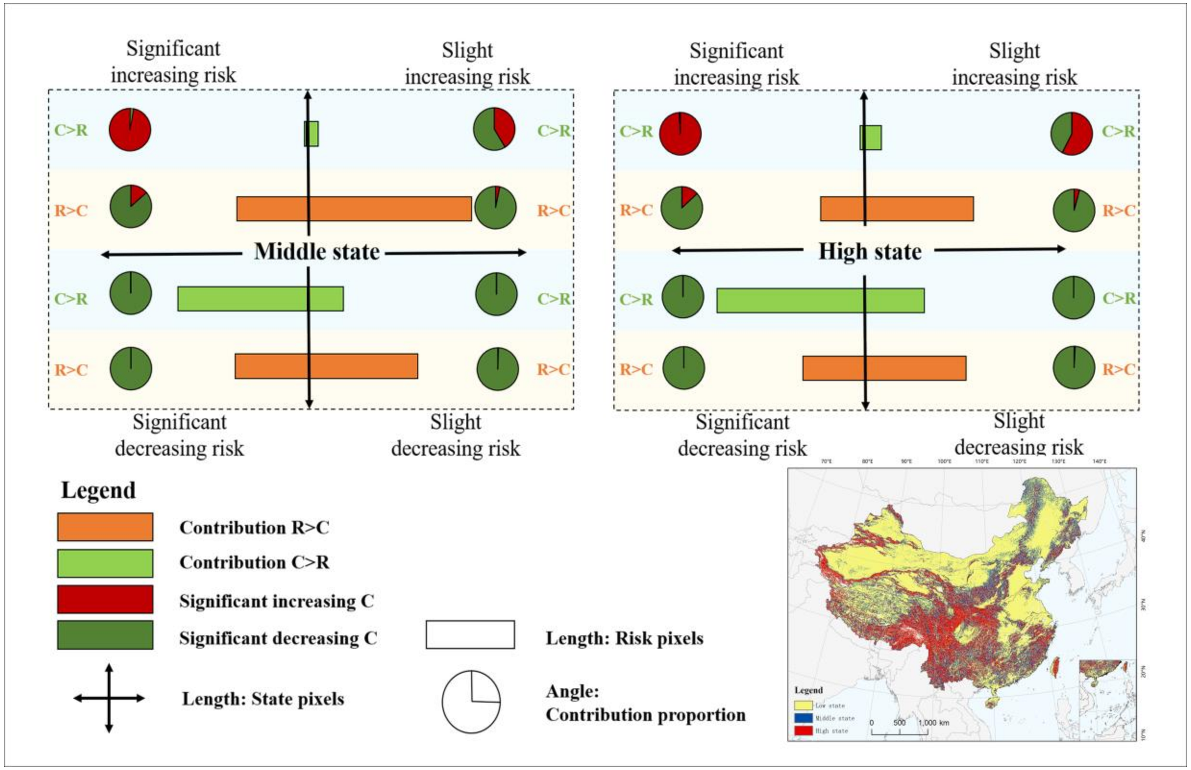


(a) Trend in percent change induced by pressure; (b) trend in percent change induced by response; (c) trend in pressure contribution; (d) trend in response contribution.

- The contribution of response in most of regions thus has increased, while that of pressure has an opposite trend.

- The vegetation greening can better offset the increasing rainfall stress in China.

The indicator contributions based on the classification of risk



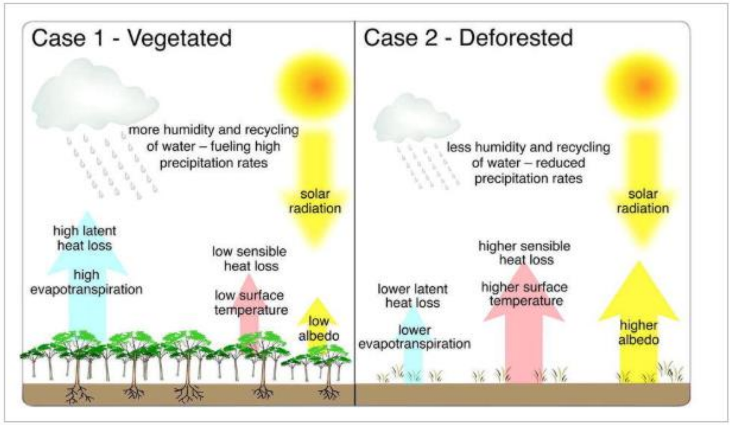
The contribution of pressure (R-factor) and response (C-factor) to the change of water erosion risk in middle and high-state regions.

- The pixels with decreasing risk are much more than the pixels with increasing risk.
- Among the four groups of increasing risk, the pixels with response contribute more than pressure accounts for 1-7% of the changed areas. By contrast, the pixels with response contribute more than pressure accounted for 20-73% among the four groups of decreasing risk.
- Among the four groups of decreasing risk, the pixels with a significantly increasing C factor are rare.

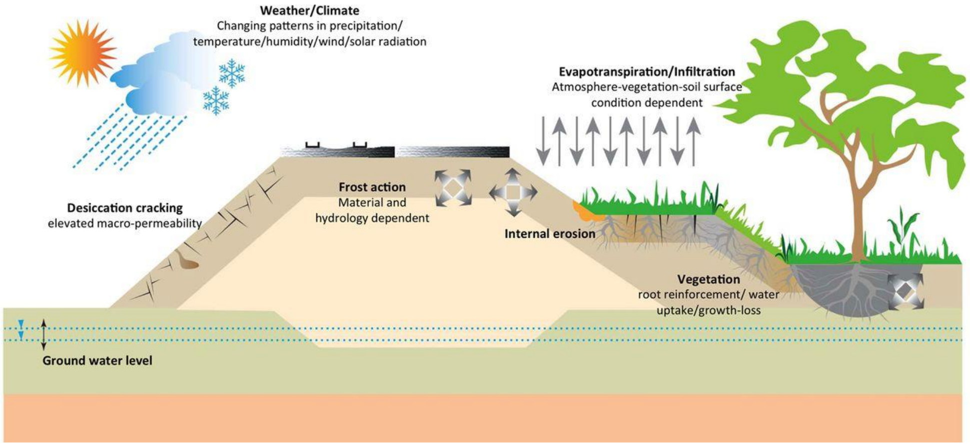
Vegetation greening can mitigate risk via partially offsets the risk of rainfall pressure, while vegetation browning may exacerbate the risk in the opposite way.

The countervailing effect of greening on increased rainfall pressure

Vegetation greening enhances the interception of rainfall, increases the penetration of rainfall, reduces the soil detachment of the increased rainfall, and decreases the sediment transport capacity by reducing the watershed runoff, thereby reducing the basin soil erosion. Vegetation coverage can effectively reduce the functional connectivity of the watershed, blocking the flow path of runoff within the watershed, and reducing sediment transport.



Effects of forest changes on water balance, boundary layer flux and climate.



Interaction of atmosphere, vegetation and soil

OUTLINE

1. Background
2. Data & Methods
3. Results and Discussion
4. Summary

04 Summary

1. A decreasing pattern was observed in water erosion risk over the first two decades of the implementation of the GFGP. Afforestation practices are effective ways to mitigate the risk of water erosion.

2. Vegetation greening can mitigating water erosion via partly offsets increasing rainfall pressure. Considering the decreasing pressure contribution and increasing response contribution, the increasing rainfall stress can be better offset by vegetation greening.

3. The contribution of vegetation greening to water erosion changes is limited in the north, and greatly contributed in the south. Afforestation in the north needs to balance the water demands of species and local environmental water availability. Afforestation in the south needs to prioritize the restoration of native forests and plantation of mixed forests over monocultures.

THANKS